Free Flight Program

Performance Metrics
Results to Date

June 2002
Report

INTRODUCTION

This is the fifth semi-annual report on Free Flight Program (FFP) performance metrics. The Free Flight Program Office established a metrics team and an initial set of performance metrics early in the Free Flight Phase 1 program, in collaboration with aviation stakeholders (represented by the RTCA Free Flight Steering Committee). The metrics team now includes research analysts, database specialists, and air traffic controllers from the following organizations: the FAA, MITRE Center for Advanced Aviation System Development (CAASD), The CNA Corp. (CNAC), Northrop Grumman Information Technology, Seagull Technology, Analytics Associates, and the National Center of Excellence for Aviation Operations Research (NEXTOR). The purpose of this effort is to establish accountability, provide near term feedback to implementation teams, and provide a basis for future free flight investments. This report focuses on performance analyses of the Traffic Management Advisor (TMA), updates previous analyses of the User Request Evaluation Tool (URET), and introduces a description and usage statistics for the Collaborative Routing Coordination Tools (CRCT). There is no discussion of other Collaborative Decision Making (CDM) initiatives or Surface Movement Advisor (SMA) in this document, since implementation and benefit measurement for these programs has been completed and reported in previous metrics reports.

The Free Flight Program was originally referred to as Free Flight Phase One (FFP1). However, as the program has been extended beyond the initial phase, it is now called the Free Flight Program. Throughout this document FFP and FFP1 are used interchangeably as we adjust to the new terminology.

The primary FFP performance goals are to increase capacity (of both airports and airspace), reduce flight time and/or distance, and improve fuel efficiency, while maintaining system safety at current levels. For user benefits calculations, the metrics examined translate into delay savings after normalization for factors such as weather and demand.

An integral part of the metrics analysis involves in-depth discussions with air traffic controllers using the FFP tools. Because many factors influence daily traffic flows, our team focuses on specific areas where controllers have observed benefits from the tools. To assure a full understanding of how each new tool affects operational performance, results across all conditions are analyzed as well as "upstream" and "downstream" effects. For example, a metering tool such as TMA has no direct link to taxi times; however, we are interested in any significant ground movement changes linked to increased arrival rates. Other measures, such as tool usage, provide supporting evidence for the validity of the primary measurements.

The following are highlights from this report:

> **URET -** The Core Capability Limited Deployment (CCLD) URET system has been deployed to six en route centers including Indianapolis and Memphis, where the prototype system has been replaced. Results show the same increased level of direct routings with the new system, indicating a successful technology transfer.

Initial findings at additional sites also indicate increases in direct routings.

TMA - TMA is now operational at seven sites, and improvements have been measured at six of these. Minneapolis, and Miami are showing an increase in their acceptance rates. Atlanta and Miami are showing an improvement in internal departure delays. Minneapolis, Dallas/Ft. Worth, Los Angeles, and Denver have shown increased actual peak arrival and operations rates. There is anecdotal evidence of benefits at San Francisco in the form of arrival stream efficiencies which have yet to be quantified.

If you have questions or comments on this document or the FFP metrics program please contact Dave Knorr at 202-220-3357 or Ed Meyer at 202-220-3407.

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1.0 SAFETY

The FFP safety metrics have been detailed in previous metrics reports. Each Operational Error (OE) and Operational Deviation (OD) at an FFP1 site has been evaluated to see if any FFP1 tool was identified as a contributing factor. As of June 1, 2002, no FFP1 capability had been identified as a factor in any OE or OD. In addition, there have been no reports involving FFP1 capabilities in any accident or incident in the National Transportation Safety Board (NTSB) Accident/Incident Reports, the FAA Incident Data System, or the FAA NMAC Database as of June 1, 2002. To date, one NASA ASRS report has been submitted (DFW, December 2000) in which a pilot claimed "the computer" (presumably CTAS) assigned his aircraft to a runway that kept him high and fast on final approach. The pilot reported that he "barely made the [descent] parameters for a stabilized [approach]." No further negative consequences from this incident have been reported.

1.1 Next Steps

As the fielding of FFP1 capabilities proceeds, the FAA will take the following steps to evaluate any safety impacts:

- Continue the analysis of OE and OD rates and severities at current and planned FFP1 sites,
- Continue the comparison between OE and OD rates and severities at FFP1 sites with those found at sites not hosting FFP1 capabilities,
- In coordination with FAA AAT-20, continue to expand the capability to analyze individual OE reports, identifying factors that may be common across multiple OEs, and
- Continue to track available safety reporting systems to identify any references to FFP1 tools as factors in OEs/ODs, incidents, or unsafe situations.

2.0 USER REQUEST EVALUATION TOOL (URET)

URET continues to produce user benefits in both prototype locations, Indianapolis (ZID) and Memphis (ZME) Air Route Traffic Control Centers (ARTCCs), through increased direct routings and reductions in static altitude restrictions. This section updates previous reports with usage statistics and distance savings from both these facilities, and presents some initial findings from Kansas City (ZKC), Cleveland (ZOB), and Chicago (ZAU) Centers.

The production version of URET, known as the Core Capability Limited Deployment (CCLD), was deployed to six FFP1 Centers between December 2001 and April 2002. ZKC began using the system in December 2001. ZID and ZME switched from prototype to CCLD operation, and ZOB initiated use, in January 2002. In February 2002 URET became available to ZAU controllers, and Washington (ZDC) Center started using the system in April. Our experience with URET prototypes at ZID and ZME leads us to believe that similar user benefits will accrue at the other FFP1 sites once the majority of controllers are suitably trained.

2.1 Description

The key URET capabilities for FFP1 include:

- Trajectory modeling,
- Aircraft and airspace conflict detection,
- Trial Planning to support conflict resolution of user or controller requests, and
- Electronic flight data management.

URET processes real-time flight plan and track data from the Host computer system. These data are combined with local airspace definitions, aircraft performance characteristics, and winds and temperatures from the National Weather Service to build four-dimensional flight trajectories for all flights within or inbound to the facility. URET also provides a “reconformance” function that continuously adapts each trajectory to the observed position, speed, climb rate, and descent rate of the modeled flight.

Once implemented, neighboring URET systems will exchange flight data, position, reconformance data, and status information in order to model accurate trajectories for all flights up to 20 minutes into the future.

URET maintains “current plan” trajectories (i.e., those that represent the current set of flight plans in the system) and uses them to continuously check for aircraft and airspace conflicts. When a conflict is detected, URET determines which sector to notify and displays an alert to that sector up to 20 minutes in advance. Trial planning allows a controller to check a desired flight plan amendment for potential conflicts before a clearance is issued. The controller can then send the trial plan to the Host as a flight plan amendment.

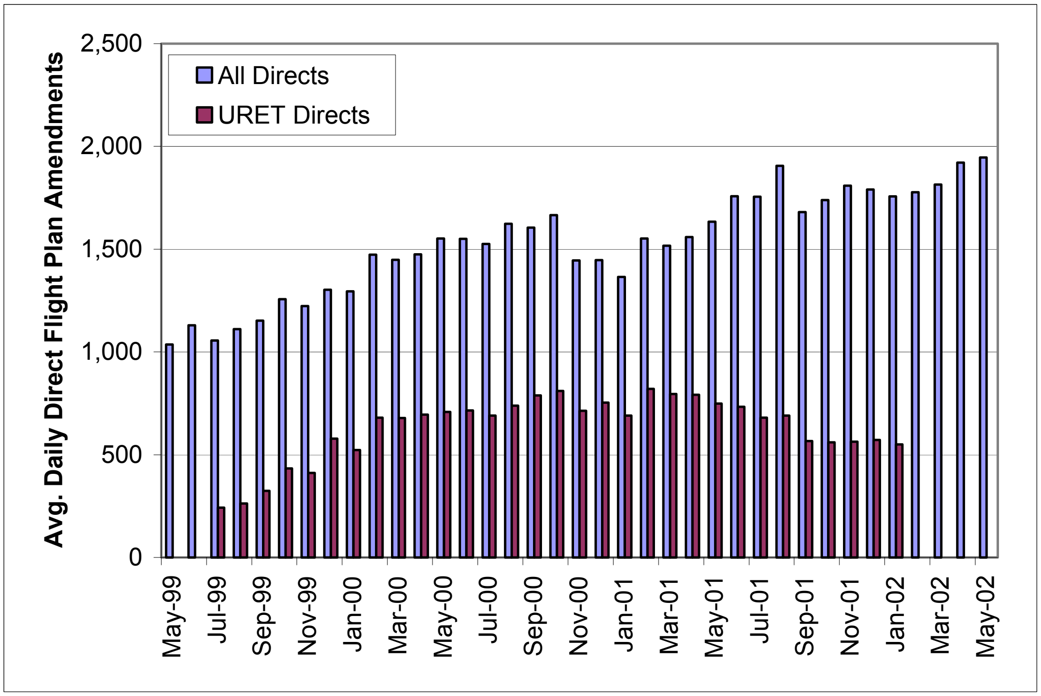
These capabilities are packaged behind a Computer Human Interface (CHI) that includes both textual and graphical information. The text-based Aircraft List helps the controller manage flight data electronically, reducing the dependence on paper flight strips. The Plans Display manages the presentation of current plans, trial plans, and conflict probe results for each sector. The Graphic Plan Display (GPD) provides a graphical capability to view aircraft routes and altitudes, predicted conflicts, and trial plan results. In addition, the point-and-click interface enables quick entry and evaluation of trial plan routes, altitudes, or speed changes, and enables the controller to send flight plan amendments to the Host. For more details about URET capabilities, benefits, and the operational concept, please refer to Reference 3.

2.2 Operational Use

2.2.1 URET at ZME and ZID

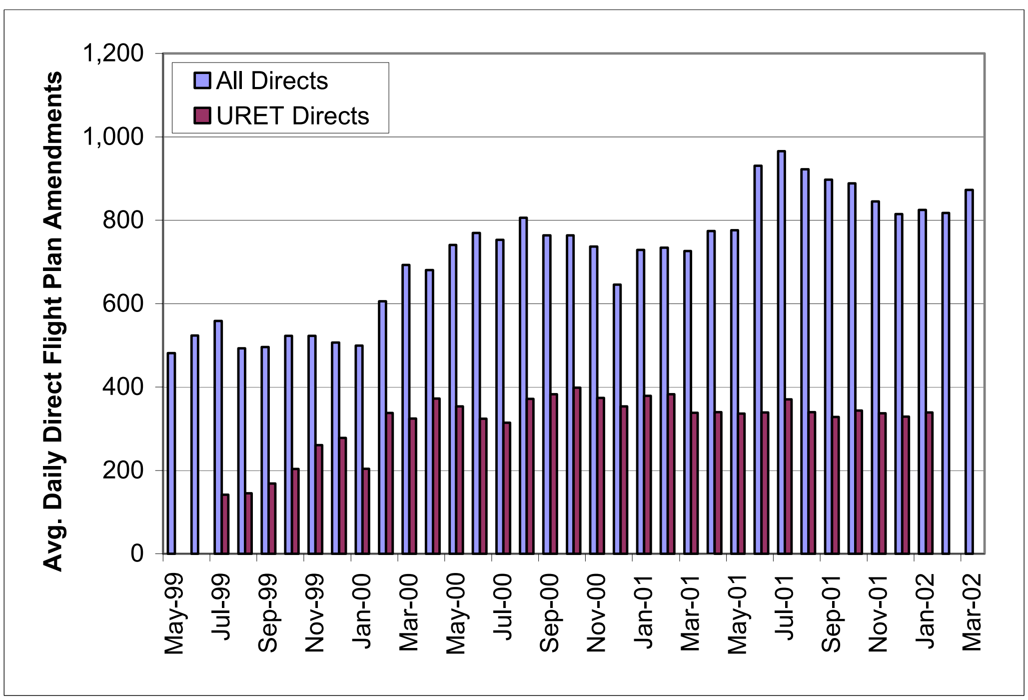
To date, analyses of the impact of URET on operational performance are based on experiences at the prototype sites, ZID and ZME. Data obtained directly from the Host and the URET prototype at ZID and ZME allowed measurement of the number direct amendments and the distance saved because of URET initiated amendments. Direct routes are those that decrease distance, measured from the point of the amendment to the destination airport. While similar data from URET CCLD is expected, the software necessary for this measurement has yet to be implemented. Figures 2-1 and 2-2 show the total number of direct amendments and the number of URET-initiated direct amendments at ZID and ZME, respectively. Data are included for the 10 hours a day at each facility with the most traffic on the two busiest days of the week (Wednesday and Thursday). Note that MITRE's ability to count URET-initiated direct amendments ended with the installation of CCLD in January 2002. Likewise, MITRE's ability to count the total number of directs at ZME ended in March 2002, but they still receive this data for ZID. Alternative means to estimate the number of direct amendments and distance savings using ETMS data are currently under development.

Both figures show a significant increase in flight plan amendments resulting in direct routings since July 1999, when the URET capability was extended to allow amendments to be sent directly to the Host. Although CCLD, installed in January 2002, currently does not allow measurement of URET direct amendments, we see that the *total* number of directs remains high, indicating that URET CCLD continues to exhibit the high level of benefit shown by the prototype system.



Based on data collected on Wednesdays and Thursdays, 1300-2300 GMT.

Figure 2-1. URET Directs as a Subset of Total Directs: ZID



Based on data collected on Wednesdays and Thursdays, 1400-2200 GMT.

Figure 2-2. URET Directs as a Subset of Total Directs: ZME

2.2.2 URET at ZKC, ZOB, ZAU, and ZDC

Kansas City Center was the first to complete installation of URET CCLD. Unlike the prototype models, URET CCLD does not currently have the ability to record usage and distance savings data. In order to gauge the usage of the system, we used ETMS data to calculate the number of flight plan amendments. If URET were to increase the number of direct amendments (as it did at ZME and ZID), this should be reflected in the total number of amendments at ZKC. The top panel of Figure 2-3 shows the total monthly number of amendments between May 2000 and May 2002. The vertical line in this figure designates the approximate date when URET achieved IDU at ZKC. Besides a seasonal effect, there is no obvious trend in the data. The middle panel of Figure 2-3 shows the same data normalized by the number of aircraft, showing a monthly average of the number of amendments per flight. In order to account for the seasonal effect, we examine the percent change from the year before in the number of amendments per flight in the bottom panel of Figure 2-3. In this figure we see a clear and consistent five month increase in the number of amendments per flight after the introduction of URET at ZKC.

Figure 2-4 similarly displays the percentage change in the number of flight plan amendments per flight for Cleveland and Chicago Centers. Both of these locations also show a large increase after the introduction of URET. At the time of this writing, we considered it too early to identify a trend at ZDC.

As updates to URET CCLD occur, we should be able to directly measure the number of URET-initiated directs.

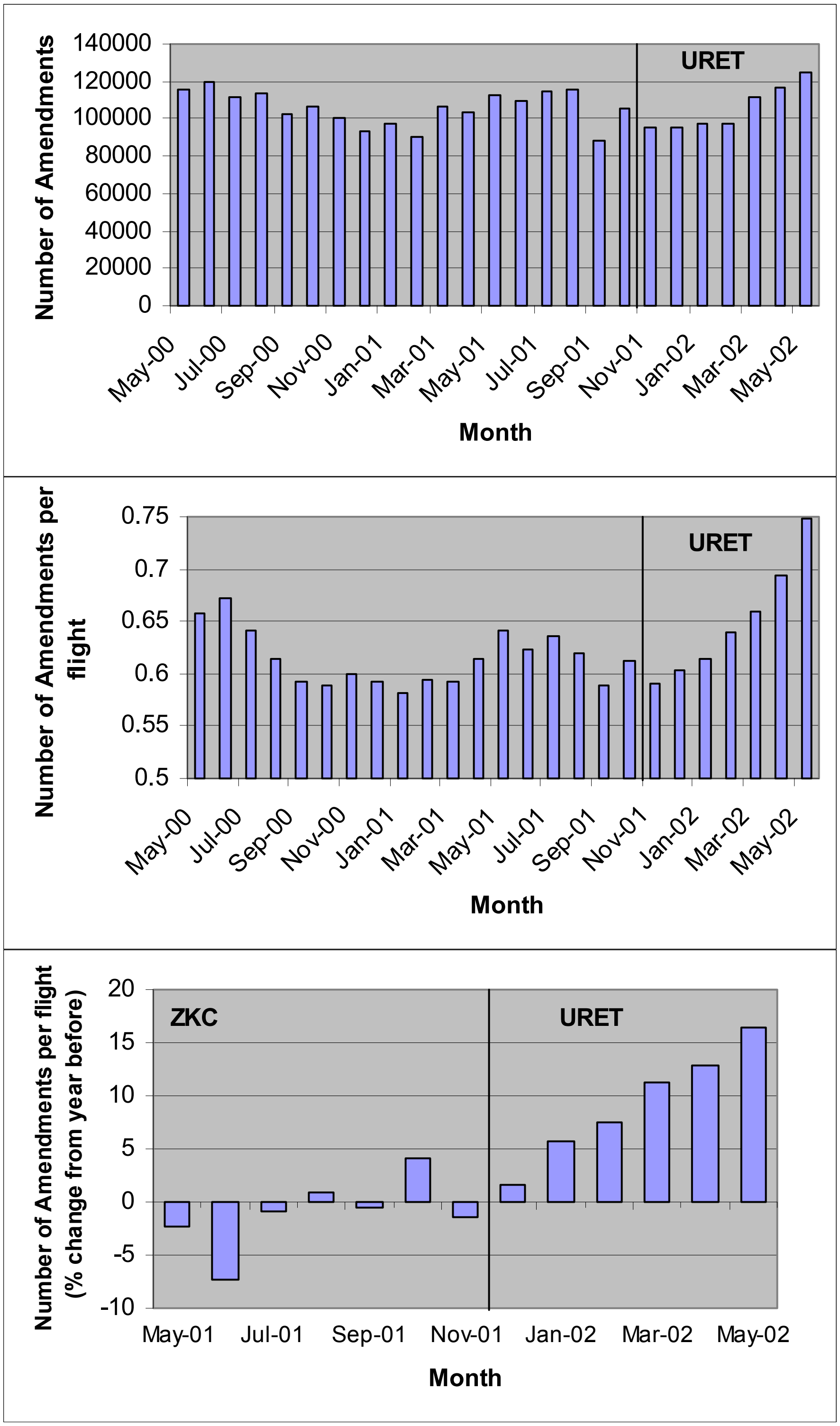
2.3 Metrics Used

The primary metrics that address URET benefits to NAS users are distance/time saved, static altitude restrictions lifted, and increased airspace capacity. A more complete description of the distance and altitude restriction metrics may be found in the FFP1 June 2001 report (Reference 6).

Several measures were employed to estimate the distance savings facilitated by URET. These measures include:

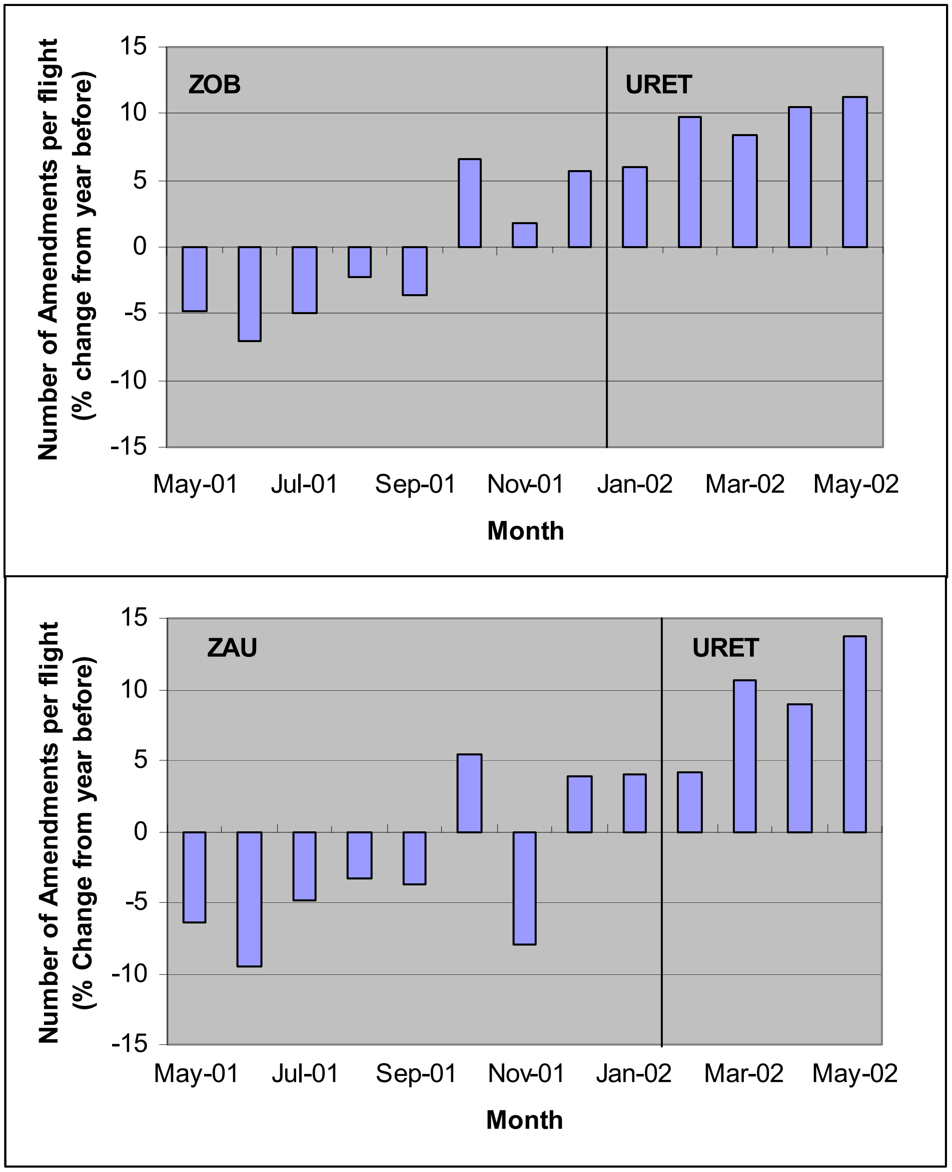
- Change in distance flown because of lateral amendments
- Change in average distance flown through each Center’s airspace
- Change in distance flown for specific city pairs.

In addition to distance savings, there have been improvements in fuel efficiency resulting from the removal of altitude restrictions. The ZID and ZME Procedure and Benefits team was established to evaluate and modify or remove altitude restrictions. Once URET is deployed to all bordering Centers, ZID should have increased opportunity to eliminate inter-facility restrictions.



Top: Total number of amendments per monthat ZKC. Middle: Average number of amendments per flight per month. Bottom: Percent change from year before in the average number of amendments per flight per month.

Figure 2-3. Flight Plan Amendments as a Measure of URET Usage at ZKC



Percent change in average number of amendments a month per flight at ZOB (Top) and ZAU (Bottom).

Figure 2-4. Flight Plan Amendments as a Measure of URET Usage at ZOB and ZAU

2.4 Analysis and Results

2.4.1 Summary of previous results

The primary measure used for the reduction in distance flown is based on data captured directly from URET. We examined all lateral flight plan amendments entered into the Host, and computed the distance savings for each. In the December 2001 metrics report, we reported an average distance savings over the baseline of approximately 3,800 nmi per Center (the baseline is defined as prior to the URET two-way Host interface). An update to this analysis is included in the next section.

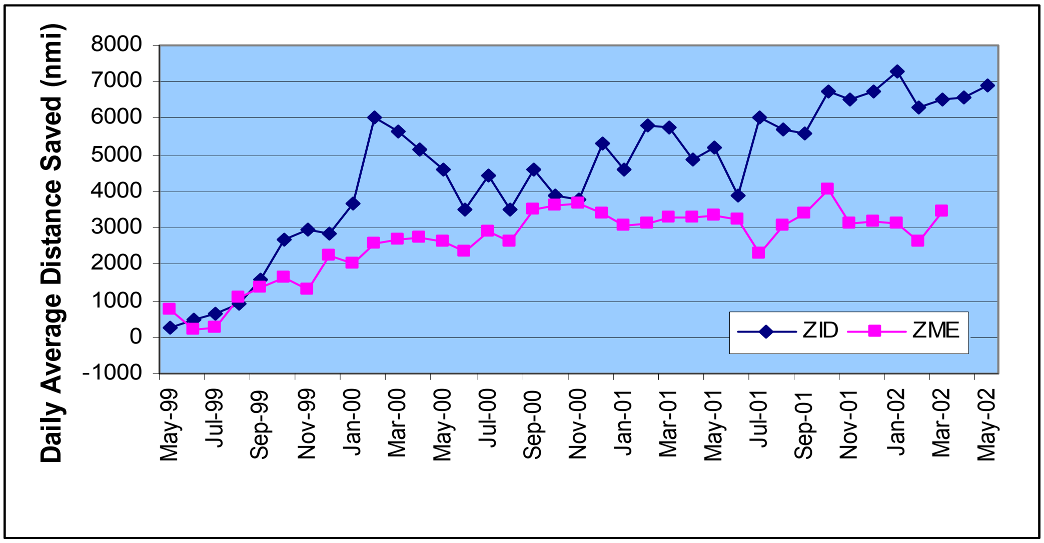
Previous reports also describe two other metrics, *Excess Distance in Center* and *En Route Distance*. Both of these measures support the results derived from the analysis of lateral amendments. Excess distance is defined as the difference between the actual distance flown and the great circle distance from the Center entry to exit points. For simplicity, we assumed that the great circle route was the most efficient route of the flight. The excess distance at ZID and ZME was compared to that at other non-URET Centers from January 2000 through August 2001. We also calculated the en route distance between selected city pairs for flights traversing ZID and ZME airspace over a two-year period (May 1999 to August 2001). The trend in the en route distance indicated a slight decrease in distance between these city pairs, but the slopes of these trends was not statistically significant. For details on the methods used to calculate these metrics see the June 2001 metrics report (Reference 6). For graphs of the final results mentioned above, see the December 2001 report (Reference 7).

The Procedure and Benefits teams at ZID and ZME were established to evaluate static altitude restrictions for modification or removal. Both centers clearly indicated that they were unwilling to consider lifting restrictions with non-URET centers. The team at ZID identified candidate restrictions for evaluation, tested the restrictions by lifting or modifying them for a period of time to determine feasibility, and determined that approximately twenty of them could be permanently modified or removed. By removing restrictions at sector boundaries, aircraft can fly longer at higher (more fuel efficient) altitudes. The June 2000 metrics report (Reference 4) describes the methodology used to determine fuel burn savings for the removed restrictions. Fuel savings were calculated based on aircraft type and nominal fuel burn at different altitudes. This analysis yielded an annual fuel savings at ZID of approximately one million gallons. We expect that this savings will increase with increased removal of restrictions and cooperation between URET-equipped Centers.

2.4.2 Lateral Amendments at ZID and ZME

Lateral flight plan amendments are defined as those that change the direction of an aircraft but not necessarily its altitude. They include increases (e.g., turns to avoid congestion or heavy weather areas) as well as decreases in distance. The distance saved metric captures the average of the daily sum of distance changes resulting from lateral amendments. Distance saved is computed from the point of the amendment to the destination airport. The data include *all* lateral amendments entered into the Host for the specified time, not just URET amendments. Figure 2-5 presents the total distance savings from lateral amendments for ZID and ZME by month. Currently, the URET prototype continues to collect this data at ZID. ZME benefit data collection will resume when the URET CCLD data collection algorithms become operational.

Distance savings from lateral amendments have increased from approximately 500 nmi daily (May and June 1999, before URET could send amendments to the Host) to approximately 5,000 nmi through Spring 2002. Note that this metric should increase in the post-September 11th era, since, with fewer aircraft flying, there should be less congestion and consequently more direct routings.



Based on data collected on Wednesdays and Thursdays, 1400-2200 GMT at ZME, 1300-2300 GMT at ZID.

Figure 2-5. Distance Saved from Lateral Amendments

2.4.3 En route Times in URET Centers

To gauge the effectiveness of a Center tool such as URET, it is helpful to use NAS-wide metrics which allow comparison relative to other ARTCCs. In previous reports (References 4-7) we have reported a slight decrease in the en route distance between city pairs for flights which cross ZID or ZME. We expect this decrease in en route distance to be apparent in en route times as well, and we also expect the magnitude of any URET city-pair time savings to be high relative to savings at city pairs outside the URET Centers. To examine this effect, we compared en route times between selected city pairs from ASPM (Reference 8) over four consecutive winters (December through February 1998-1999, 1999-2000, 2000-2001, and 2001-2002). The flights selected are those between the 31 busiest airports as reported in the FAA Benchmark study (Reference 10). Winter was chosen so as to minimize any seasonal effects caused by summertime convective weather.

Table 2-1 lists city pairs with significant chamges in average actual airborne times. The upper part of Table 2-1 shows the twenty city pairs which had the largest percentage decreases in actual airborne times over the four winters. The bottom part of Table 2-1 displays city pairs with significant percentage increases in airborne times. Figure 2-6 displays the city pairs in Table 2-1 with decreases in airborne time on a ARTCC map of the NAS with ZID and ZME highlighted. Note that nine of the twenty city pairs with decreased times cross ZID or ZME, and none of the city pairs with increased times cross URET air space.

We also examined changes in flight plan estimated times en route. A decrease in estimated flight times may indicate either a decrease in the actual flight times or an increase in the predictability of flight times. Table 2-2 lists significant changes in the average estimated flight times between the selected city pairs. Figure 2-7 displays the city pairs that had decreases in estimated flight times. As in the case of actual airborne times, nine of the top twenty decreases occur in URET airspace, and none of the significant increases occur in either ZID or ZME.

We have attempted to account for seasonal effects by using only the winters. However, we acknowledge that the measurement of airborne time is heavily influenced by the winds and aircraft mix. For this reason, we have not used these results to actually quantify URET user benefits. Rather, we present this analysis as qualitative supporting evidence of the benefit of the system, quantified by our other primary metrics.

2.4.4 NEXTOR URET Analysis

Researchers with the National Center of Excellence for Aviation Operations Research (NEXTOR) at UC Berkeley have conducted an independent study of the effects of URET on airspace users, which is documented in Appendix A. The NEXTOR study has two distinguishing features. First, a quasi-experimental method was adopted, which compares flights that use URET sectors to those that do not, where the latter are used as a control group, and the former as the treatment group. This approach eliminates effects of NAS-wide performance trends that could be confused with the impacts of URET in a simple before-and-after analysis. Second, NEXTOR focused exclusively on "end-to-end" metrics rather than metrics based on portions of flights within ZID and ZME. This approach has the advantage of capturing any upstream or downstream impacts of the new capability, or any diminution of the URET benefit as aircraft proceed into non-URET Centers. On the other hand, by using metrics that capture the entire flight it becomes more difficult to control for other extraneous factors, making it harder to discern small changes to flights that occur in URET Centers.

The NEXTOR analysis revealed a modest decrease in airborne times for flights in ZID and ZME following URET introduction, which is consistent with our other analyses. Additionally, their analysis revealed a substantial decrease in ground delay for flights that enter ZID and ZME airspace. While we acknowledge that URET benefits could manifest themselves upstream at departure airports, the magnitude of the benefits reported by this study is larger than we would have anticipated. Other, coincident events may have precipitated these changes. UC Berkeley researchers are continuing to investigate this possibility.

Table 2-1. Trends in Average Actual Airborne Times

ZID ZME	Origin	Destination	Average Actual Airborne Time '98-'99	'99-'00	'00-'01	'01-'02	Avg. Anuual % Change
	IAD	CLE	81	77	69	61	-8.9
✓	MEM	IAH	99	84	80	78	-7.6
	CLE	IAD	65	63	57	52	-7.1
	PHL	JFK	33	32	28	27	-5.9
✓	MEM	CVG	73	71	68	62	-5.2
	CLT	ATL	53	51	51	46	-4.4
	PHL	DCA	36	36	33	32	-4.1
✓	CLT	CVG	77	76	72	68	-3.9
	BWI	JFK	51	50	49	46	-3.6
	DCA	BOS	68	65	63	61	-3.4
✓	CVG	CLT	65	64	61	59	-3.2
	ORD	JFK	99	95	92	90	-3.2
	JFK	BWI	54	53	53	49	-3.1
✓	IAH	JFK	176	175	173	162	-2.8
✓	MEM	DFW	79	75	74	73	-2.7
	DCA	EWR	45	44	43	42	-2.6
✓	DTW	CVG	50	49	47	46	-2.4
✓	MEM	ATL	55	53	53	51	-2.2
✓	LAS	CLT	219	216	208	206	-2.0
	MIA	BWI	129	128	127	121	-2.0
	MCO	MIA	47	48	50	50	2.0
	MSP	JFK	121	123	127	129	2.2
	SAN	LAX	23	25	26	27	5.3
	LAX	SAN	23	23	25	28	7.1
	LGA	BWI	40	44	56	56	12.7

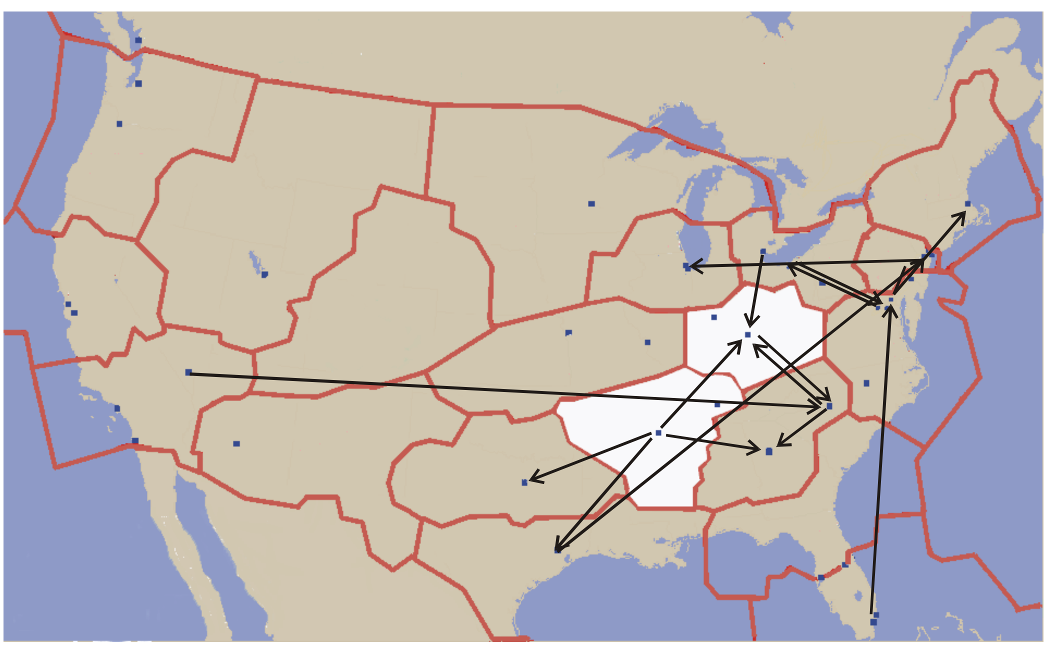


Figure 2-6. Twenty City Pairs with Largest Percentage Decreases in Actual Airborne Times, Winters 1998 – 2001

Table 2-2. Trends in Average Estimated Time En Route

ZID ZME	Origin	Destination	Average Estimated Air Time ’98-’99	’99-’00	’00-’01	’01-‘02	Avg. Anuual % Change
✓	MEM	CVG	76	73	66	58	-8.3
✓	MEM	IAH	98	85	78	77	-7.5
	IAD	CLE	72	68	60	57	-7.4
✓	CVG	CLT	73	65	63	58	-7.3
	CLE	IAD	62	58	51	50	-6.8
✓	CLT	CVG	80	76	73	66	-6.0
✓	CVG	MEM	80	79	76	68	-5.3
	JFK	BOS	43	41	39	37	-4.6
✓	MEM	STL	57	53	51	50	-4.4
	PHL	DCA	33	32	30	29	-4.3
	DCA	EWR	43	42	40	37	-4.3
	BWI	JFK	48	48	44	43	-4.1
	DCA	PHL	29	28	27	26	-3.7
	IAD	JFK	53	51	49	47	-3.6
✓	IAH	JFK	176	175	173	158	-3.3
	BOS	PHL	70	65	64	63	-3.2
✓	CVG	DTW	43	43	41	40	-2.8
✓	DFW	MEM	65	64	60	60	-2.7
	EWR	SLC	287	280	278	274	-2.7
	DTW	CLE	26	25	25	24	-2.6
	PHL	IAD	41	43	43	44	2.9
	PHL	EWR	23	24	25	26	3.5
	DFW	IAH	41	42	42	46	3.7
	CLE	PIT	31	31	34	39	9.0
	PIT	CLE	34	34	40	45	10.6
	BWI	LGA	36	42	51	52	13.2

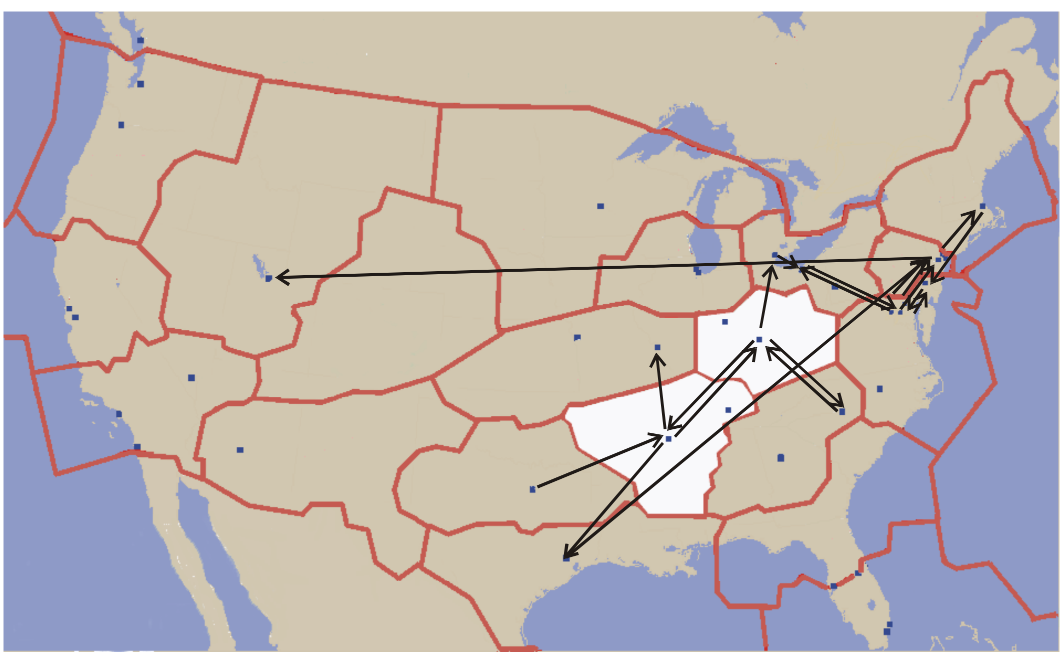


Figure 2-7. Twenty City Pairs with Largest Percentage Decrease in Estimated En Route Times, Winters 1998 - 2001

3.0 CENTER-TRACON AUTOMATION SYSTEM (CTAS)

The Center-TRACON Automation System (CTAS) consists of two major components. Traffic Management Advisor (TMA) is currently operational at Ft. Worth, Minneapolis, Denver, Los Angeles, Atlanta, Miami, and Oakland ARTCCs. Activity on the TRACON component of CTAS, the Passive Final Approach Spacing Tool (pFAST), was terminated because of the tool's inability to function adequately in dynamic situations. An alternative component, CTAS-Terminal, was developed and is in use at the Southern California TRACON (SCT). This section describes the operational use of these tools at the FFP1 sites, outlines the analyses used in measuring benefits, and presents some results. More specifically, the results include a summary of previous findings for Ft. Worth, Minneapolis, and Denver Centers; an updated analysis of the effect of TMA on Airport Acceptance Rates (AARs) at MSP; an updated analysis of the effects of CTAS on acceptance rates and actual arrival rates in Los Angeles Center and Southern California TRACON; and introductory studies performed for Atlanta, Miami, and Oakland Centers.

3.1 Description

TMA assists controllers in the en route cruise and transition airspace around major airports by providing them with a means of optimizing arrival throughput. By optimizing throughput, TMA helps to reduce arrival delays. The resulting uniformity of arrival flows can also lead to an increase in departure rates and a decrease in departure delays. Inputs to the TMA system include real-time radar track data, flight plan data, and a three-dimensional grid of wind speeds and directions. TMA's trajectory models use this information, updated every 12 seconds, to compute routes and optimal schedules to the TRACON meter fixes for all arriving IFR aircraft, with consideration given to separation, airspace, and airport constraints.

3.2 Operational Use

3.2.1 TMA at ZMP/MSP and ZDV/DEN

The TMA computer interface incorporates two primary strategic displays. The Timeline Graphical User Interface (T-GUI) displays estimated time of arrival, CTAS-computed delay, scheduled time of arrival, and runway assignment for each track in the TMA area of regard. The Planview Graphical User Interface (P-GUI) displays aircraft arriving at an airport in two dimensions (i.e., as seen from above). TMU managers use these and other displays to determine if and when time-based metering needs to be imposed in the Center's airspace so that the arrival rate specified by the TRACON is not exceeded. When metering is imposed, floor controllers see a sequence list overlaid on their radar displays that indicates which aircraft need to be delayed and by how much. Initial Daily Use (IDU) of TMA at Minneapolis Center (ZMP) for arrivals into Minneapolis/St. Paul International Airport (MSP) began June 2000, and Denver Center (ZDV) started IDU for Denver International Airport (DEN) arrivals in September 2000. In June of 2001, MSP TRACON began receiving a TMA feed that gives traffic managers the opportunity to observe Center metering efforts. It is hoped, that this feed will increase situational awareness and foster cooperation between the Center and TRACON, allowing for higher Airport Acceptance Rates (AARs) and a smoother flow into the airport.

3.2.2 CTAS at ZLA/LAX and SCT/LAX

3.2.2.1 CTAS-Terminal

As the installation and adaptation of pFAST progressed at SCT, it became apparent that operations were different from those for which pFAST was designed, and significant changes to the program code would have to be made in order for the original implementation to work effectively. However, the facility personnel determined that they could achieve improvements in situational awareness without the tool providing suggested runway assignments and sequence numbers. This implementation uses auxiliary displays to provide controllers at key positions with a broader view, encompassing traffic from outside the TRACON airspace all the way to the runway. Because the implementation at SCT differs greatly from the original product tested at DFW, and to avoid confusion, the Free Flight Program Office now refers to this capability as CTAS-Terminal. IDU of CTAS-Terminal started in February 2001, and Planned Capability Available (PCA) status was achieved in August 2001.

As originally designed, pFAST supplies suggested runway assignments and sequence numbers for arrival aircraft to the controllers. pFAST also has plan view (P-GUI) and timeline view (T-GUI) displays that are normally installed in the Traffic Management Unit for planning purposes. Because CTAS-Terminal gets information from the ARTCC long-range radar, as well as the TRACON short-range radar, these supplemental displays can convey the "big picture" of the traffic situation better than other traditional displays. Further, these displays show the current data block information regardless of which sector controller may be entering or updating the data. At SCT, this additional information is given to the two LAX final controller positions and the two primary LAX feeder sectors, through additional displays installed at those operating positions.

3.2.2.2 TMA

Regular active use of TMA started at ZLA for LAX in June 2001. The ZLA implementation of TMA is somewhat different from that described for ZMP and ZDV (Section **3.2.1**). Until mid May 2002, TMA was primarily a strategic tool used by ZLA traffic managers to determine the necessity of location-based miles-in-trail (MIT) restrictions. The overlay list that allows tactical use of the tool by individual controllers was not in use at ZLA because the Center was not using time-based metering. ZLA began time-based metering with TMA on a test basis in May 2002 and is expected to fully employ time-based metering in the near future. Early anecdotal evidence indicates that time-based metering significantly improves the flow of aircraft into LAX. Data collection is underway and the FFP Metrics Team will be conducting a thorough analysis of the benefits of this test.

The TMU also indicated a mechanism by which TMA decreases the amount of gate delay for internal departures. Traffic into LAX is dominated by large flows coming from airports external to ZLA. Traffic to LAX from airports within the Center must wait for gaps in this flow in order to get clearance to depart. This frequently causes long ground delays for aircraft trying to fly to LAX from these local airports. A feature named the "Departure Scheduler" in TMA allows the TMU to accurately determine the duration of gaps in the flow and grant more clearances for these internal departures.

3.2.3 TMA at ZTL/ATL, ZMA/MIA, and ZOA/SFO

TMA is also installed at Atlanta Center (ZTL), Miami Center (ZMA), and Oakland Center (ZOA) for arrivals into Atlanta Hartsfield International (ATL), Miami International (MIA), and San Francisco International (SFO) Airports. IDU began at ZTL in February 2001, at ZMA in May of 2001, and at ZOA in September 2001. None of these Centers currently uses time-based metering. Rather, TMA is used as a strategic tool by the TMUs, similar to its use at ZLA. Although further installation of CTAS-Terminal seems unlikely at the affected TRACONs, each TRACON will receive a Center TMA feed (like the one in use at MSP). We anticipate that this feed will increase situational awareness in a manner similar to CTAS Terminal at SCT.

3.3 Metrics Used

The TMA evaluation at each of the FFP1 sites focuses on safety, capacity improvement, and efficiency of user operations. Safety has already been discussed in Section 1.0 of this report. FFP1 capacity metrics for TMA seek to address the following issue:

• *Does TMA increase peak-period throughput at airports where it is implemented?*

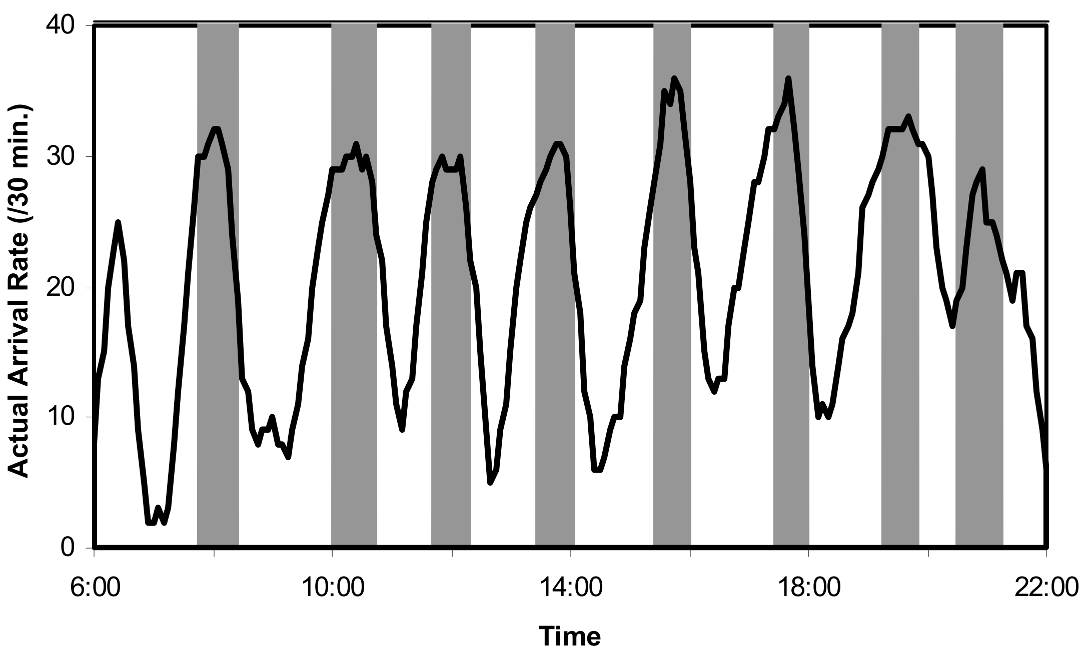
We anticipate that by smoothing the flow of arriving traffic during arrival peaks TMA metering will help TRACON controllers to land more airplanes in a given period. Thus our primary TMA capacity metrics are:

- Airport Acceptance Rate (AAR)
- Actual peak-period arrival rate.

It is also possible that by making arrival flows more predictable, TMA will help TRACON and tower controllers depart more aircraft during arrival peaks. This is especially true at MSP where arrivals and departures frequently share runways. For MSP we also include the capacity metric of:

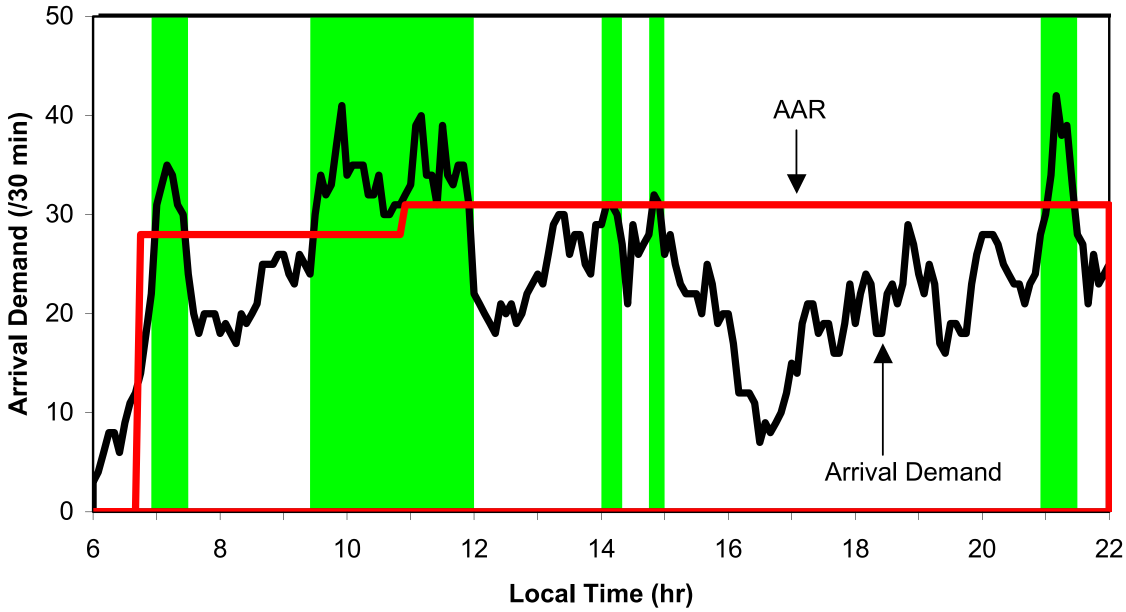
- Actual peak-period operations rate (arrivals plus departures).

The analysis of these metrics relies on determining peak arrival periods at the airport in question. Figure 3-1 illustrates the arrival rate for a typical day at MSP while Figure 3-2 shows a similar plot of arrival demand for LAX. At MSP there are seven distinct arrival peaks resulting from Northwest Airlines hub scheduling practices, and one or two somewhat less distinct peaks between 19:30 and 20:30 local time. LAX, on the other hand, is not a major hub, and therefore does not have clearly defined peaks that occur each day. We use different methods to determine peak periods at these different airports. At MSP, we use an algorithm to isolate peaks from arrival data that identifies the closest-spaced 30 aircraft during periods when the arrival rate is greater than the day's average arrival rate. To determine peak periods at LAX, we compare the arrival demand to the reported AAR, where we define arrival demand as the maximum of the actual arrival rate (calculated from TRACON data) and the estimated arrival rate (calculated from ETMS actual take-off time plus the filed flight time). Peaks in the actual rate demonstrate stress at the runway, while peaks in the estimated rate quantify the number of flights that wanted to land, thereby revealing stress in the surrounding airspace. Those times for which the arrival demand was greater than the AAR are the stressed periods. For us to include a period for analysis, the duration of the heightened arrival demand had to be longer than 15 minutes. This represents a rather strict measure of stress that should be considered a lower bound on the amount of time the airport is under pressure. Figure 3-2 shows the arrival demand and the AAR at LAX. Shaded sections indicate periods when the arrival demand was greater than the AAR. Since this type of analysis relies heavily on the AAR, we do not consider times when it was not recorded. After we use a technique to determine peak periods, we then compute an equivalent hourly arrival rate for this period. The hourly arrival rate then becomes one observation for subsequent statistical analysis.



Shading indicates peak periods.

Figure 3-1. Example of Arrival Rate at MSP



Shaded areas indicate arrival demand greater than AAR.

Figure 3-2. Example of Arrival Demand and AAR at LAX

3.4 Analysis and Results

3.4.1 Summary of previous TMA results

TMA was initially implemented at Ft. Worth Center before the establishment of the Free Flight Phase 1 program, concurrent with the redesign of Dallas/Ft. Worth terminal airspace, so no applicable baseline data is available for this site. The impact of TMA at Dallas/Ft. Worth was analyzed by the NASA Ames Research Center (Reference 9), and was discussed in the June 2000 metrics report (Reference 4). No further analysis of this site is envisioned.

Denver Center (ZDV) uses TMA for arrivals at Denver International Airport (DEN). Although controllers employ time-based metering at DEN, airport capacity is such that the facility does not require it on a regular basis. In order to study the effect of TMA, we limited the times of study to those in which the airport was heavily stressed. In the December 2001 report (Reference 7), we presented an analysis of the arrival peaks during times of high airport stress, which showed that the arrival rate increased by 1 to 2 aircraft an hour after introduction of TMA. Most of the time, air traffic managers use TMA to make strategic decisions about miles-in-trail (MIT) restrictions. We expect that benefits due to TMA will increase at ZDV/DEN as demand increases.

At Minneapolis Center (ZMP), TMA is used both as a strategic planning tool by the Traffic Management Unit (TMU) and tactically by controllers who are actively controlling aircraft using time-based metering. Initial Daily Use (IDU) of TMA at ZMP for Minneapolis International Airport (MSP) began in June 2000. An analysis of TMA presented in the June 2001 metrics Report (Reference 6) concluded that operations rates increased by approximately three an hour during arrival peaks. The analysis also revealed a decrease in flight times close to the terminal area during arrival peaks, which correlates to an increase in efficiency. This analysis was updated in the December 2001 metrics report (Reference 7) to show the continuation in throughput and efficiency benefits, even after the decrease in demand after September 11th. The December 2001 report also described an increase in the AAR at MSP during instrument conditions after the installation of a TMA TRACON feed. In the next section, we update the analysis of AARs at MSP.

A preliminary analysis of CTAS at ZLA and SCT for arrivals at LAX was presented in the June 2001 metrics report. The throughput analysis showed an increase in the difference between the actual arrival rate and the AAR for peak periods. Efficiency analyses presented in the June 2001 report showed a slight decrease in the flight times and distances for arriving traffic during peak periods, and a queuing study that indicated an average decrease in delay of 1.63 minutes after CTAS implementation. An update of the throughput analysis, presented in the December 2001 report, concluded that arrival throughput at LAX had increased between one and two airplanes an hour during the peaks. Also, in the December 2001 report, we probed efficiency by examining individual tracks to show a decrease in holding. We also showed a decrease in delay for internal departures resulting from TMA. In the following sections, we further update the throughput analysis at LAX with more data, and revisit delay on internal departures.

3.4.2 MSP Airport Acceptance Rate Analysis

When examining the impact of a change in automation or procedures at an ATC facility, we typically begin by examining the rates that the facility is specifying, to see if any change has occurred; for TMA at MSP, this means the AAR. We examined AARs at MSP from 1 October 1999 through 30 April 2002 in order to see if the TRACON has increased rates since TMA was implemented.[1] TMA became operational at ZMP/MSP in late June 2000, but we have elected to exclude data from 15 June 2000 to 15 July 2000 from this analysis because of uncertainties concerning the status of the system during that period. We have also excluded data from September 2001 because of the sharp decrease in demand immediately following September 11th. The data for these analyses were obtained from facility logs, which were reviewed each day. AAR changes were entered in the FFP1 operational performance database.

We first conducted a simple Analysis of Variance (ANOVA) on the AAR log entries, weighted by the length of time for which each entry was in effect. We used two factors in this analysis: a TMA factor, representing the use of TMA (which commenced in the summer of 2000); and an IFR factor, indicating when instrument approaches were in use. The interaction between these two factors was also included. We found no detectable

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[1] While we have data prior to 1 October 1999, there was taxiway construction activity at the airport prior to this date. Consequently AARs were lower at that time.

change in AAR following TMA introduction using this methodology (the same result that we reported earlier in Reference 7).

We then took another look at the potential change in AAR at MSP, focusing on the introduction of TMA displays into the TRACON. Typically, when TMA is implemented in an ARTCC, display repeaters are also installed at the associated TRACON. These displays provide TRACON traffic managers with improved knowledge of the traffic that will shortly be entering their airspace. Traffic managers at the DFW TRACON reported that this improved knowledge allowed them to increase arrival rates for their airport. Because of a renovation of the MSP TRACON, the TMA displays were not available until July 2001. We repeated the ANOVA described above, but this time compared the base case (pre-TMA) to the period starting on 18 July 2001, when TMA was fully operational at the ARTCC *and* TMA displays were operational at the TRACON. Again, the data for September 2001 were not included in this analysis. The results of this ANOVA indicate a significant interaction between the TMA and IFR factors. Because of this, we elected to conduct a linear regression of the impact of these factors on the AAR. In the December report we found that before November 2001, TMA did not impact AAR by itself, but it did have an impact when coupled with instrument approaches variable (IFR). We reexamined this result for data through April 2002.

Table 3-1 presents the AAR regression results. The regression indicates that TMA not only has an impact on AAR when coupled with instrument approaches, but it also has an effect by itself, indicating an effect during visual approaches. On average, the AAR is about 1.4 arrivals per hour greater during instrument approaches and 0.7 greater during visual approaches following the introduction of TMA to the ARTCC and the TRACON. This result is statistically significant at the five percent level.

3.4.3 LAX Throughput Analysis

Using a similar approach to the one taken at MSP, we first performed a linear regression analysis on the AARs at LAX to see if Southern California TRACON (SCT) has detectably raised acceptance rates since implementation of CTAS-Terminal at SCT and TMA at ZLA. A similar analysis performed for the December 2001 report found no increase in AAR up to that time. The current analysis includes data from February 2000 through April 2002. CTAS-Terminal became available to SCT in February 2001. Like MSP, we use instrument conditions (IFR), tool implementation (CTAS, in this case), and the interaction between the two as variables. Acceptance rates at LAX are also heavily affected by airport configuration, so a variable (East Config.) was included to account for this large variation. Table 3-2 displays the results. The East Config. and IFR variables have large negative effects on the AAR. The significance of the CTAS variable indicates that CTAS has had limited impact on the AAR. However, the interaction between CTAS and IFR produces an increase in the AAR of approximately one an hour. We conclude that following implementation of CTAS there has been a small but significant increase in the called acceptance rate during times when instrument approaches are in use. This result is similar to that seen at MSP in the December 2001 report.

Table 3-1. MSP Arrival Acceptance Rate Regression

Dependent Variable: AAR weighted by minutes in configuration

	R Square	Adjusted R Square	F	Sig.
	.237	.236	427.033	.000

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
(Constant)	59.341	.109		546.684	.000
IFR	-5.521	.183	-.502	-30.247	.000
TMA	.669	.195	.059	3.433	.001
TMA*IFR	.706	.318	.044	2.220	.026

	Explanation of Variables
IFR	0 = Visual approaches, 1 = Instrument approaches
TMA	0 = pre-TMA, 1 = post-TMA
TMA*IFR	Correlation between TMA and IFR

Table 3-2. LAX Arrival Acceptance Rate Regression

Dependent Variable: AAR weighted by minutes in configuration

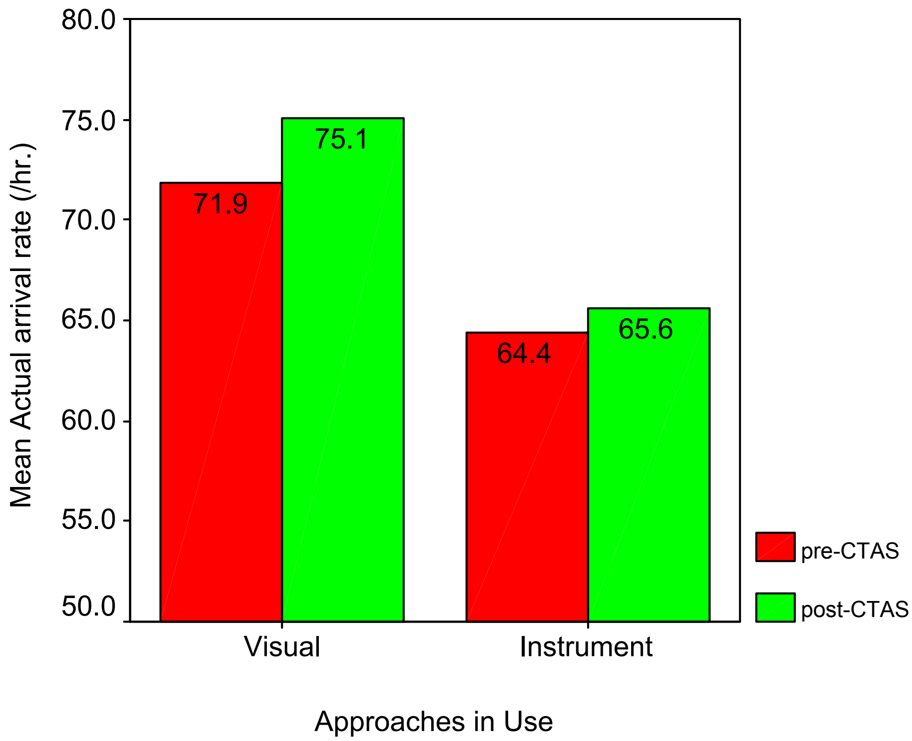
	R Square	Adjusted R Square	F	Sig
	.326	.325	359.023	.000

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
(Constant)	76.202	.168		453.522	.000
East Config	-12.732	.665	-.289	-19.156	.000
IFR	-8.921	.374	-.523	-23.872	.000
CTAS	-.351	.263	-.024	-1.332	.183
CTAS*IFR	1.060	.519	.050	2.041	.041

	Explanation of varaibles
East Config	0 = West airport configuration , 1 = East or Ocean configuration
IFR	0 = Visual approaches, 1 = Instrument approaches
CTAS	0 = pre-CTAS, 1 = post-CTAS
CTAS*IFR	Correlation between CTAS and IFR

In an analysis of throughput, we are also interested in the actual peak arrival rate seen at the airport. This section updates the analysis done for the December 2001 report, in order to include data for at least one year following CTAS implementation. As in the AAR analysis, the sample set includes data from February 2000 through April 2002, with CTAS IDU starting in February of 2001.

For each peak period at LAX (identified by the method described in Section **3.3),** we calculate an hourly arrival rate. Figure 3-3 presents the mean peak arrival rates before and after CTAS implementation for both visual and instrument approaches. This simple comparison suggests that peak arrival rates are higher since CTAS implementation. As expected, the rates are lower for instrument conditions.



Mean actual arrival rate at peak time periods for different airport conditions from February 2000 - October 2001, weighted by peak duration. Annotation designates mean value.

Figure 3-3. LAX Mean Actual Arrival Rate

To support this result, we also performed a regression on the arrival rate, in which we included several variables relating to airport conditions, weather, and fleet mix. Table 3-3 displays the results of the regression. The overall regression is statistically significant, as suggested by the large value of the F statistic, but the adjusted R^2 statistic indicates that the model only accounts for approximately 46 percent of the variation of the dependent variable. The coefficients of the model all have the expected signs. The percentage of heavy aircraft, instrument approaches, rain, wind gust speed, and the airport being in an East configuration (requiring aircraft to land from the ocean side) all have negative effects on the arrival rate. The arrival rate increases due to increases in the visibility, ceiling, or the inboard usage (inner runways used for both arrivals and departures). The CTAS variable has a positive coefficient of 1.672, suggesting that the CTAS tools help to increase the arrival rate between one and two airplanes an hour during peak arrival periods. This result is very similar to the one presented in the December 2001 report.

Table 3-3. Actual Arrival Rate Regression Results

	R Square	Adjusted R Square	F	Sig.
	.465	.464	273.850	.000

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
(Constant)	66.175	.612		108.041	.000
Inst. Approach	-3.640	.329	-.187	-11.050	.000
CTAS	1.672	.303	.087	5.512	.000
East configuration	-5.672	.648	-.140	-8.753	.000
Pct. heavy aircraft	-12.004	2.187	-.082	-5.488	.000
Rain	-3.180	.695	-.074	-4.574	.000
Inboard usage	6.237	.333	.328	18.715	.000
Gust speed	-.223	.052	-.066	-4.307	.000
Visibility	.192	.048	.064	3.965	.000
Ceiling	1.598E-04	.000	.251	13.828	.000

	Explanation of variables
Inst. Approach	0 = Visual Approaches, 1 = Instrument approaches
CTAS	0 = pre-CTAS, 1 = post-CTAS
East configuration	0 = West airport configuration, 1= East or Ocean configuration
Pct. heavy aircraft	Percentage of total aircraft during peak which are heavy
Rain	0 = no rain in surface weather report, 1 = rain in report
Inboard usage	0 = Inboards not in use, 1 = inboards in use
Gust speed	Surface gust velocity in knots
Visibility	Surface visibility in statute miles
Ceiling	Ceiling in feet with unlimited ceiling replaced with 35,000 ft.

The regression results indicate that there continues to be an increase in peak arrival throughput, even though the demand at LAX has yet to recover from the effects of September 11th . Before September 2001, the arrival demand tended to be greater than the AAR for approximately 20 percent of the day, leading to many peak observations. After September 2001, the demand rose again quickly, but still hovers around 80 percent of its previous value. Consequently, the amount of time the arrival demand exceeds the AAR has decreased significantly, as has the number of observations available for the regression. The results of the regression then tell us that, even though the demand has decreased, the actual arrival throughput during times when the airport is stressed is higher after the implementation of CTAS at LAX. We expect that the tactical use of TMA for time-based metering (which started on a test basis in May 2002) will also increase the throughput at LAX.

3.4.4 MIA Airport Acceptance Rate Analysis

Even though MIA has yet to start time-based metering using TMA, some effects have been seen at this facility. At MIA, TMA went IDU in May 2001. Prior to TMA daily use, the TRACON kept the AAR at a consistent 62 arrivals per hour. Because of the increased coordination between the TRACON and the Center (ZMA) after TMA, MIA began to change the AAR based on airport and environmental conditions. Figure 3-4 displays the average AAR before and after TMA. Since we had incomplete log data before TMA IDU at this facility, the data source for this analysis is ASPM (Reference 8). The pre-TMA period represents a year of data before IDU (June 2000 – May 2001) and the post-TMA data measures from IDU through May 2002 (June 2001 – May 2002). Figure 3-4 shows that the average AAR has increased from 62 to 66 an hour since TMA, indicating a larger potential capacity at the airport. In May 2002, MIA started calling rates as high as 72 and received actual arrival counts as high as 74 an hour. These results imply a potential for sustained increased throughput as demand levels continue to rise.

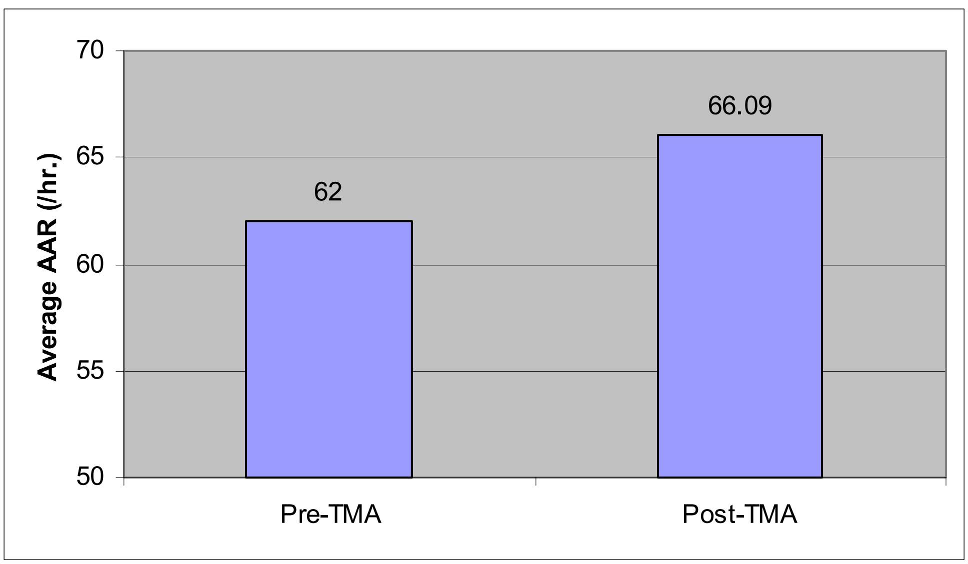


Figure 3-5. Mean AAR at MIA

Because the AAR is now more sensitive to airport and environmental conditions, it is not surprising to find that the Center can do a better job of delivering the desired rate. Specifically, we found that during periods of airport stress (we limited this to times when the actual arrival count exceeded 80 percent of the AAR) the difference between the AAR and the actual rate has decreased significantly, indicating that the Center is delivering a closer match to the AAR now that the AAR changes.

ZMA and MIA TRACON personnel have substantiated these findings and attribute them to increased situational awareness, better coordination between the facilities, proper front-loading, and shorter and more tactical miles-in-trail restrictions.

3.4.5 TMA and Internal Departures

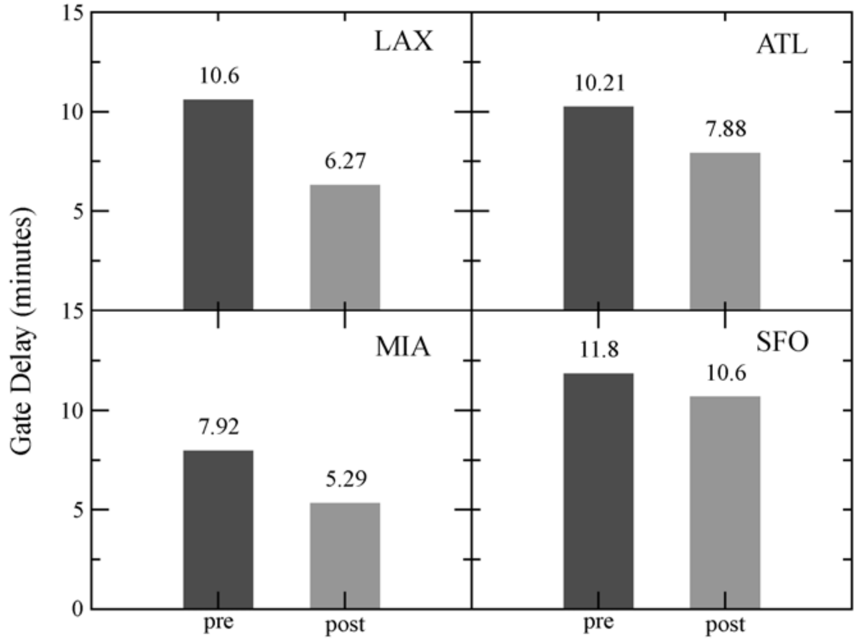
In places where time-based metering is not used, the Traffic Management Units (TMUs) have discovered other mechanisms by which TMA can positively effect airport arrivals. One of these is the use of the TMA "Departure Scheduler," which allows Traffic Management Coordinators (TMCs) to trial-plan arrivals from internal airports.

Each ARTCC has a number of internal airports that are placed on an "Approval Request" (APPREQ) status by the TMU. APPREQ status requires the affected Airport Air Traffic Control Tower (ATCT) to obtain approval from the TMU before releasing aircraft whose destination is a large airport (ATL, LAX, etc.) to which TMA is metering. The purpose of the APPREQ status is to allow the TMU to evaluate the departure aircraft's relative position to those aircraft already in the airborne arrival stream and assign a departure time to merge the aircraft into this overhead flow. The TMC will evaluate the requested departure time and either approve this time, assign a release time (with a clearance void time, if necessary), or route the aircraft over another arrival fix.

TMA provides a suggested departure time for each arrival route, and calculates the imparted delay needed to fit the aircraft into the arrival flow for the selected fix. The TMC uses this information to make informed decisions on when to release aircraft, or whether to reroute aircraft. Additionally, the TMA time-lines provide visual cues to the TMC for affected airports and proposed departure times. This allows the TMC to be proactive in evaluating internal departures.

To assess the impact of TMA on internal departures, we compiled delay data for the affected flights from the Aviation System Performance Metrics (ASPM) database. We looked at both gate delay (at the departure airport) and airborne delay, choosing not to consider taxi-in or taxi-out delays, since they do not seem relevant to TMA usage. We calculated average delay per flight for the airports that require a release by ZLA, ZTL, ZMA, and ZOA for departures to LAX, ATL, MIA, and SFO respectively. We limited the analysis to those airports that average more than one flight per day. We compared averages for pre-TMA (historical average from a year before IDU) to post-TMA (from IDU through April 2002). In the case of ATL, IDU for TMA started in February 2001. Upon talking with facilty personnel, we learned that the tool was not used regularly until June 2001. For this analysis we therefore assume June 1, 2001 to be the time at which TMA started to have an effect at ZTL.

Figure 3-5 displays the average gate delay for internal departures, and Figure 3-6 shows the average airborne delay. Gate delay for internal departures has decreased significantly at all four airports studied. The decrease is largest at LAX, where a CTAS tool has been in place for the longest time (since February 2001), while the smallest decrease is evident at SFO, the airport that started IDU most recently (TMA started IDU at SFO in September 2001).

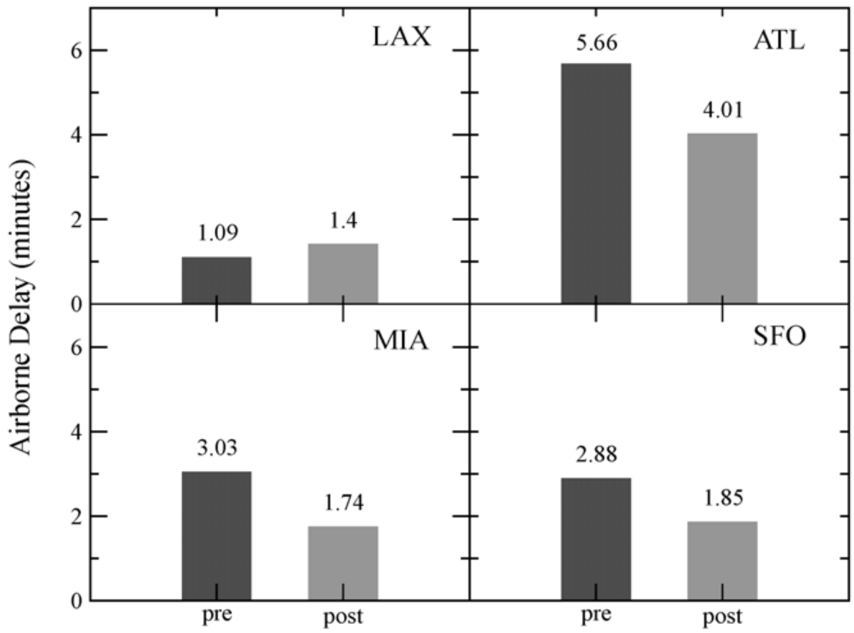


pre includes 1 year of data before IDU, post includes IDU to April 30 2002

Figure 3-6 Effect of TMA on Gate Delay for Center Internal Departures

The effect of TMA on airborne delay is somewhat more ambiguous. ATL, MIA, and SFO airports have seen a decrease in airborne delay for internal departures since TMA IDU, while LAX has seen a very slight increase (less than half a minute). In the December 2001 report we found a decrease in the airborne time for internal departures from six specific airports to LAX that were released by ZLA. The current analysis is different in that it takes into account all internal airports, including many released by both ZLA and SCT.

From this internal departure data, we conclude that TMA has a significant effect on gate delay for the affected aircraft through use of the TMA Departure Scheduler. As TMUs become more familiar with this tool, their ability to use TMA to fit aircraft into the complicated arrival streams increases.



pre includes 1 year of data before IDU, post includes IDU to April 30 2002

Figure 3-7 Effect of TMA on Airborne Delay for Center Internal Departures

4.0 COLLABORATIVE ROUTING COORDINATION TOOLS (CRCT)

The Collaborative Routing Coordination Tools (CRCT) Concept Development and Evaluation Platform (CDEP) is deployed at ZID and ZKC, and at the Air Traffic Control System Command Center (ATCSCC). Some functionality similar to that of the CRCT CDEP has been implemented in the Enhanced Traffic Management System (ETMS). This section discusses the use of the CRCT CDEP and similar functionality in ETMS by Traffic Management Coordinators (TMC), and the perceived benefit of this use.

4.1 Description

The CRCT suite is an integrated collection of automation functions designed to assist traffic flow management in monitoring traffic flows, developing strategies to alleviate congestion and to plan for severe weather, and analyzing the impact of proposed strategies. With the CRCT analysis capabilities, the traffic manager is able to visualize the impact of a proposed strategy on sector loading or on an individual aircraft, and compare different strategies.

The main functions of the CRCT CDEP are:

- NAS Monitor - displays the alert status of the twenty ARTCCs in the contiguous United States.
- NAS Sector Demand - provides sector count projections for several hours in the future for each of the twenty ARTCCs. This feature includes the Sector Count Monitor and Time in Sector functionality.
- Traffic Flow and Demand Analysis - identifies flights that are planned to operate through a defined airspace and characterizes the demand on that airspace. This feature includes the Traffic Display, Future Traffic Display (FTD), and Flow Constrained Area (FCA) functionality.
- Aircraft Reroute Definition - permits graphical or textual definition of reroutes for a group of flights or for individual flights.
- Reroute Evaluation - permits evaluation of the potential impacts of reroutes on sector volume, spacing, and traffic density.
- Playbook - graphical depictions of the National Playbook.

The Flow Evaluation Area (FEA)/FCA functionality currently implemented in ETMS is similar to the CRCT CDEP FCA functionality. ETMS features the additional capability to share this information betweenn facilities and with airspace users.

4.2 Operational Use

4.2.1 CRCT CDEP at ZID/ZKC and ATCSCC

Until March 31, 2002, CRCT CDEP had been governed by a Memorandum of Understanding between the FAA and the National Air Traffic Controllers Association (NATCA) that established the CRCT Core Team. This agreement enabled use of the

CRCT CDEP during the evaluation period to compare and validate CRCT functionality with existing traffic management tools, but did not allow CRCT CDEP to be used as the sole source of decision-making. In this context, the CRCT CDEP has been used by TMCs in the Traffic Management Units (TMU) at ZID and ZKC to facilitate their monitoring, analysis, and evaluation tasks. CRCT CDEP has not been used extensively by TMCs at the ATCSCC.

TMCs at ZID and ZKC report four routine uses of the CRCT CDEP functionality:

- TMCs, and frequently Area Supervisors, refer to CRCT's Sector Count Monitor to maintain an awareness of predicted sector loads. The Sector Count Monitor is usually displayed by default at one of the two CRCT positions in each of the TMUs. Alerts often prompt further investigation via the Time in Sector, FCA, and FTD functionality.
- When adjacent centers request miles-in-trail (MIT) restrictions, TMCs often use the CRCT FCA and FTD functionality to identify the affected flights. FCAs are drawn around the boundaries with the downstream Center (and sometimes the upstream Center) and are often filtered by destination. TMCs use the FTD functionality to scroll the traffic display through time to look for groups of flights that will require spacing for restrictions.
- When TMCs anticipate congestion in a sector, they sometimes create an FCA to identify affected flights. Often, this action is taken to better understand the dynamic nature and volume of the traffic. The FTD and FCA Demand Graph functionality are used for this purpose as well. Just as frequently, the TMC creates an FCA to identify flights that will be subject to intervention in some preconceived mitigation strategy.
- TMCs also use CRCT FCA functionality to identify flights that will need to change their routes to avoid severe convective weather. Similarly, TMCs will draw FCAs around the gaps in lines of thunderstorms to monitor the number of flights using this airspace to avoid severe weather.

The CRCT CDEP is occasionally used for less routine activities, such as the evaluation of the impact of Strategic Plans of Operations (SPO). The CRCT Reroute functionality is used infrequently.

4.2.2 CRCT Functionality Implemented in ETMS

The Flow Evaluation Area (FEA) function implemented in ETMS is similar to CRCT CDEP's FCA functionality. The FEA function is available to all Centers and the ATCSCC; training began in the spring of 2002. Already, the FEA function has been used by TMCs in Centers other than ZID and ZKC to evaluate the necessity of MIT restrictions.

Additionally, the ATCSCC has the ability to transform FEAs into public FCAs, made available to airlines via the web-based Common Constraint Situation Display (CCSD). In particular, airlines are sent lists of flights that intersect the FCA, which is also included in a Traffic Advisory and discussed during Strategic Planning Teleconferences. One airline has remarked on the benefits of this shared situational awareness in flight planning. In fact, the FAA can also be made aware of airline actions taken to implement collaborative strategies: airlines can include the notation "FCA" in the remarks section of flight plans, which indicates to FAA facilities that they should avoid further delays, reroutes, or altitude changes.

4.3 Analysis and Results

Analysis of automated usage logs reveals regular use of the CRCT CDEP at ZID and ZKC, although there is large variability over days. TMCs at ZID typically create two to four FCAs daily; TMCs at ZKC create about one to three. Neither Center uses reroute definition or evaluation functionality frequently.

The TMCs have indicated that they perceive the information the CRCT CDPEP provides to be insightful. Discussions with TMCs indicate that the use of the CRCT CDEP sometimes allows them to pursue more timely, precise, and effective strategies than they would otherwise. This includes the possibility of avoiding some action that might otherwise have been thought necessary. This theme is common to a number of perceived benefits of CRCT CDEP to airspace users.

- *Accuracy and Timeliness of Alerts*. Several TMCs believe that CRCT CDEP's Sector Count Monitor provides more accurate future sector loads and quicker alerts of anticipated violations of sector volume thresholds than they have been provided in the past. Improved accuracy naturally decreases unnecessary intervention and improved timeliness requires less dramatic action. Both minimize disruption to user operations.

- *Precise Use of Miles-In-Trail Restrictions*. The frequent use of MIT restrictions by TMCs to balance demand and capacity entails significant potential for underutilization of airport and airspace resources. A common decision made by TMCs is whether to "pass back" a restriction, i.e., to request that traffic upstream of the center be restricted, and, if so, what type and extent of restriction to request. Barring additional information about demand, a rule of thumb is to multiply the miles-in-trail for some restriction imposed on the Center by the number of streams to be merged, e.g., if merging two streams to meet a 10 miles-in-trail restriction, the Center might request 20 miles-in-trail restrictions on both. This rule offers decent protection (as only internal departures need to be fit into a restricted stream), but is often unwarranted by the actual demand. TMCs report that use of CRCT FCA and FTD functionality allows them to better identify demand and to sometimes request a less aggressive "pass-back," to shorten its duration, or to forego a request entirely. On the other hand, better identification of demand sometimes leads to a more aggressive "pass-back" than would have otherwise been requested because difficulties in merging internal departures become apparent. The measurement of CRCT's effects on "pass-back" restrictions is the subject of ongoing analysis.

- *Precise Identification of Flights in Congested Areas*. The CRCT capability to rapidly identify flights in particular airspace allows TMCs to more quickly and less dramatically take action to mitigate congestion. TMCs report that CRCT functions allow them to identify flights whose slight adjustment would relieve congestion and, moreover, to do so earlier, making the adjustment even slighter. Furthermore, this use of CRCT functions allows TMCs to avoid “broad brush” strategies that might affect flights not contributing to congestion at all.

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ACRONYMS

AAR	Airport Acceptance Rates
ANOVA	Analysis of Variance
ARTCC	Air Route Traffic Control Center
ASP	Arrival Sequencing Program
ASPM	Aviation System Performance Metrics
ATC	Air Traffic Control
ATCSCC	Air Traffic Control System Command Center
ATL	Atlanta Hartsfield International Airport
CAASD	Center for Advanced Aviation System Development
CCLD	Core Capability Limited Deployment
CHI	Computer Human Interface
CNAC	Center for Naval Analysis Corporation
CODAS	Consolidated Operations and Delay Analysis System
CTAS	Center TRACON Automation System
DEN	Denver International Airport
DFW	Dallas/Ft. Worth International Airport
DR	Discrepancy Report
EDCT	Estimated Departure Clearance Time
ETMS	Enhanced Traffic Management System
FAA	Federal Aviation Administration
FDIO	Flight Data Input/Output
FFP	Free Flight Program
FFP1	Free Flight Phase 1
FFPO	Free Flight Program Office
FL	Flight Level
FSM	Flight Schedule Monitor
GAL	Gallon
GDP	Gross Domestic Product
GDP	Ground Delay Program
GDP-E	Ground Delay Program Enhancements
GMT	Greenwich Mean Time
GPD	Graphic Plan Display
HCS	Host Computer System
IDU	Initial Daily Use
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
LAS	Las Vegas McCarran International Airport
LAX	Los Angeles International Airport

LB	Pound
LOA	Letters of Agreement
MIA	Miami International Airport
MIT	Miles-in-Trail
MOU	Memorandum of Understanding
MSP	Minneapolis/St. Paul
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NATCA	National Air Traffic Control Association
NEXTOR	National Center of Excellence for Aviation Operational Research
nmi	Nautical mile
NRP	North American Route Program
NWA	Northwest Airlines
OAG	Official Airline Guide
OD	Operational Deviation
OE	Operational Error
PCA	Planned Capability Available
pFAST	Passive Final Approach Spacing Tool
P-GUI	Planview Graphical User Interface
RAC	Radar Associate Controller
RPM	Revenue Passenger Miles
SCT	Southern California TRACON
SLI	Seal Beach Airport
SMA	Surface Movement Advisor
SOP	Standard Operating Procedures
SUA	Special Use Airspace
T-GUI	Timeline Graphical User Interface
TMA	Traffic Management Advisor
TMC	Traffic Management Coordinator
TMU	Traffic Management Unit
TRACON	Terminal Radar Approach Control Facility
URET	User Request Evaluation Tool
VFR	Visual Flight Rules
VTU	Ventura Airport
WAFDOF	Wrong Altitude For Direction Of Flight
ZDV	Denver Center
ZFW	Ft. Worth Center
ZID	Indianapolis Center
ZKC	Kansas City Center
ZMA	Miami Center
ZME	Memphis Center

ZMP	Minneapolis Center
ZTL	Atlanta Center

APPENDIX A: NEXTOR URET ANALYSIS

NEXTOR researchers at UC Berkeley have conducted an independent study of the effects of URET on airspace users, which is documented here. The NEXTOR study has two distinguishing features. First, a quasi-experimental method was adopted, which compares flights that use URET sectors to those that do not, where the latter are used as a control group, and the former as the treatment group. This approach eliminates effects of NAS-wide performance trends that could be confused with the impacts of URET in a simple before-and-after analysis. Second, NEXTOR focused exclusively on "end-to-end" metrics rather than metrics based on portions of flights within ZID and ZME. This approach has the advantage of capturing any upstream or downstream impacts of the new capability, or any diminution of the URET benefit as aircraft proceed into non-URET Centers. On the other hand, by using metrics that capture the entire flight it becomes more difficult to control for other extraneous factors, making it harder to discern small changes to flights that occur in URET Centers.

The NEXTOR analysis revealed a modest decrease in airborne times for flights in ZID and ZME following URET introduction, which is consistent with our other analyses. Additionally, their analysis revealed a substantial decrease in ground delay for flights that enter ZID and ZME airspace. While we acknowledge that URET benefits could manifest themselves upstream at departure airports, the magnitude of the benefits reported by this study is larger than we would have anticipated. Other, coincident events may have precipitated these changes. UC Berkeley researchers are continuing to investigate this possibility.

The time periods used for the NEXTOR analysis were February to July, 1999 and 2000. Data for 1999 is used as a benchmark, because URET was still not fully operational at that time. After the initiation of two-way Host communications in early July of 1999, the utilization of URET increased dramatically. Also, in February 2000, daily use of URET in ZID and ZME began. Therefore, the months from February to July 1999 are defined as the "before" period for this analysis, while the same months in 2000 are identified as the "after" period.

Data used in this analysis came from two sources: the Airline Service Quality Performance (ASQP) database and excerpts from Enhanced Traffic Management System (ETMS) data for ZID and ZME. The ASQP database contains information on all flights by the ten biggest passenger airlines in the US. The database contains scheduled departure and arrival times, actual departure and arrival times, taxi-out and taxi-in times, wheels-off and wheels-on times, and various time intervals between these times. ASQP has no data on route flown, however. Thus, in order to identify the flights that were traversing URET airspace, boundary-crossing data derived from ETMS was used. The boundary crossing data contains information for each flight that crosses ZID and ZME Center boundaries, such as flight time and flight distance within the Centers. Both the ASQP and the boundary crossing data identify flights by flight number, making it possible to link the two data sources. Thus, one can determine whether each ASQP flight used URET airspace.

Using this information, NEXTOR used simple linear models to estimate whether URET flights in the after period had lower flight times than those in the before period. For purposes of this analysis, flight time is defined as the sum of departure delay (relative to schedule), taxi-out time, and airborne time. Models are estimated for these three components as well as the overall flight time. They are thus able to identify both how flight time has been affected by URET, and what portions of the flight have been affected.

For this analysis, they estimate two models of flight times of individual ASQP flights. The models differ with respect to the way in which the impact of URET is represented. In the first model, they estimate a single coefficient representing the flight time impact of URET for all flights. From the results of that model one can say "flights that flew through URET airspace in the after period appear to have saved *x* minutes of flight time." In the second model, the URET impact is made origin and destination specific. This model supports statements such as "Flights that flew through URET airspace in the after period, and originated from airport *a*, appear to have saved *y* minutes of flight time" and "Flights that flew through URET airspace in the after period, and were bound for airport *b*, appear to have saved *z* minutes of flight time."

In order to be able to isolate the influence of URET on flight times in both models, they controlled for the influences of the following factors:

- Distance between origin and destination, which is modeled as a piece-wise linear distance function, using a great circle distance between origin and destination.
- Direction of flight, which captures the winds aloft effect, modeled as the difference between origin and destination latitudes and longitudes.
- Airport fixed effects, which account for the influences certain airports impose on flights. They use the set of 40 airports that have the highest delays.
- Differences between flight times for URET and non-URET flights that persisted through both the before and after periods.
- Overall trends in flight times in different time periods.

The two models used are:

$$FlightTime = \tau + \sum_{\ell} \alpha_{\ell} L_{\ell} + \beta_{lat} \cdot X_{lat} + \beta_{lon} \cdot X_{lon} + \sum_{i=1}^{40} [\delta_{ai} \cdot A_i + \delta_{di} \cdot D_i] + \mu \cdot URET + \pi \cdot AFTER + \theta \cdot AFTER \cdot URET \quad (1)$$

$$FlightTime = \tau + \sum_{\ell} \alpha_{\ell} L_{\ell} + \beta_{lat} \cdot X_{lat} + \beta_{lon} \cdot X_{lon} + \sum_{i=1}^{40} [\delta_{ai} \cdot A_i + \delta_{di} \cdot D_i] + \sum_{i=1}^{40} [\gamma_{ai} \cdot A_i \cdot URET_i + \gamma_{di} \cdot D_i \cdot URET] + \sum_{i=1}^{40} [\lambda_{ai} \cdot A_i \cdot URET \cdot AFTER + \lambda_{di} \cdot D_i \cdot URET \cdot AFTER] + \mu \cdot URET + \pi \cdot AFTER + \theta \cdot AFTER \cdot URET \quad (2)$$

where

L_ℓ	is the distance flown in distance range ℓ (ranges are 0-200, 200-500, 500-1000, and over 1000 nm)
X_{lat}	is the destination latitude minus the origin latitude
X_{lon}	is the destination longitude minus the origin longitude
A_i	is a dummy variable set to 1 if airport *i* is the arrival airport, 0 otherwise
D_i	is a dummy variable set to 1 if airport *i* is the destination airport, 0 otherwise
URET	is a dummy variable set to 1 if the flight is in URET airspace (ZID or ZME, or both) for more than 10 minutes
AFTER	is a dummy variable set to 1 if the flight took place in year 2000, the after period of the analysis (1999 being before)
*AFTER*URET*	is a dummy variable set to 1 if the flight took place over URET airspace in the after period of analysis
A_i*URET*	is a dummy variable set to 1 if airport *i* is the arrival airport and flight goes through URET airspace
D_i*URET*	is a dummy variable set to 1 if airport *i* is the destination airport and flight goes through URET airspace
A_i*URET*AFTER*	is a dummy variable set to 1 if airport *i* is the arrival airport and flight goes through URET airspace in the after period
D_i*URET*AFTER*	is a dummy variable set to 1 if airport *i* is the destination airport and flight goes through URET airspace in the after period
$\tau, \alpha_\ell, \beta_{lat}, \beta_{lon},, \delta_{ai}, \delta_{di}, \gamma_{ai}, \gamma_{di}, \lambda_{ai}, \lambda_{di,} \mu, \pi, \theta$	are coefficients to be estimated.

Models were estimated on six different data sets. A given data set includes all flights in the ASQP database for corresponding months of the February-July 1999 and February-July 2000 time periods (February 1999 and February 2000, March 1999 and March 2000, et cetera) that also had less than three hours of delay, with both origin and destination in the continental US. The month-by-month partitioning allows coefficient values to vary seasonally, in response to monthly differences in weather conditions and demand. Table A-1 shows the coefficient estimates of Model 1, for the month of June (to save space, estimates for airport fixed effects are not presented).

Table A-1. Individual Flight Time Coefficients for June

Coefficient	Description	Estimate	Standard Error	P-Value
τ	Intercept	24.470	0.3672	<0.0001
α_1	Distance in 0-200 nm range	0.169	0.0020	<0.0001
α_2	Distance 200-500 nm range	0.146	0.0005	<0.0001
α_3	Distance 500-1000 nm range	0.139	0.0003	<0.0001
α_4	Distance 1000+ nm range	0.131	0.0002	<0.0001
β_{lat}	Difference in latitude	3.426	0.5969	<0.0001
β_{lon}	Difference in longitude	21.890	0.2274	<0.0001
μ	*URET* dummy	4.172	0.0854	<0.0001
π	*AFTER* dummy	-1.322	0.1257	<0.0001
θ	*AFTER URET* interaction	-3.260	0.1506	<0.0001
Adjusted R^2		0.8168		
Number of Observations		840656		

It can be seen that the estimate for θ is negative. This implies that flight times for URET flights decreased more than those for non-URET flights between the pre- and post-milestone period. This difference, estimated here to be 3.3 minutes, can reasonably be attributed to URET itself.

Next, NEXTOR studied the impact of URET on flight times in more detail. The first column of Table A-2 presents estimates of θ for each of the monthly data sets, measuring the average change in flight time (in minutes) that appears to result from URET implementation. Estimates are presented both for the overall flight time and the flight time components. The θ estimates for overall flight time are all negative, and significant at the 0.01 level, for each month. The July estimates are considerably different from the others, probably because two-way Host communication was in effect for much of July 1999.

Table A-2. URET Impact Coefficients for Individual Flight Times Model (min.)*

Month	Overall Flight Time	Flight Time Component			Adjusted R^2
		Airborne	Departure Delay	Taxi-out	
February	**-1.643**	**-0.239**	**-1.392**	-0.011	0.8693
March	**-1.367**	**-0.512**	**-0.929**	**0.074**	0.8672
April	**-1.354**	**-0.452**	**-0.865**	-0.037	0.8591
May	**-1.099**	**-0.196**	**-0.929**	0.026	0.8445
June	**-3.260**	**-0.345**	**-2.828**	-0.086	0.8186
July	**-0.502**	**0.223**	**-0.751**	0.026	0.8225

*The coefficients in bold type are statistically significant at the 1% level.

From the flight time component results presented in Table A-2, we see that airborne times for URET flights generally decreased by about 15 seconds per flight between 1999 and 2000. On the other hand, much larger reductions in departure delays—around 1 minute in most cases—are observed. It appears that, somehow, URET enabled flights to depart sooner.

Table A-2 also reveals that the estimated effects of URET vary considerably from month to month. A possible explanation is that the impact of URET is weather dependent. To investigate this, they segmented the data sets by overall NAS performance, where NAS-wide average daily arrival delay was used as the performance metric. Table A-3 presents the URET impact coefficients (θ) for the segmented data sets. In general, the higher the average delay, the greater the effect of URET. The greatest disparity is in the time-at-origin effect, which is generally less than a minute for low delay days, increasing to 2-3 minutes for days with moderate delays, and to 5-6 minutes on the worst days. There is some evidence of a differential impact on airborne time as well, but this difference is much smaller, and probably insignificant statistically.

Table A-3. URET Impact Coefficients for Individual Flight Times Model, Group

Low Delay Days, Average Daily Delay < 20 min

Month	Overall Flight Time	Flight Time Component		Adjusted R^2	No. of Days Used	
		Airborne	Time at Origin**		1999	2000
February	-1.365	-0.460	**-0.905**	0.9012	23	19
March	**-0.219**	**-0.205**	-0.013	0.8925	24	22
April	**-0.409**	**-0.244**	**-0.165**	0.8982	19	21
May	**1.157**	**0.158**	0.999	0.8880	18	19
June	**-1.020**	**-0.328**	**-0.692**	0.8841	13	8
July	-0.342	**0.014**	**-0.355**	0.8805	13	15

Moderate Delay Days, Average Daily Delay, 20-40 min

Month	Overall Flight Time	Flight Time Component		Adjusted R^2	No. of Days Used	
		Airborne	Time at Origin**		1999	2000
February	**-1.068**	**-0.092**	**-0.977**	0.8127	4	8
March	**-4.623**	**-1.553**	**-3.070**	0.8086	7	8
April	**-2.189**	**-0.762**	**-1.427**	0.8218	9	7
May	**-4.100**	**-0.683**	**-3.417**	0.8053	13	8
June	**-3.023**	**-0.541**	**-2.482**	0.8154	12	17
July	**-1.329**	**0.264**	**-1.593**	0.8145	13	10

High Delay Days, Average Daily Delay > 40 min

Month	Overall Flight Time	Flight Time Component		Adjusted R^2	No. of Days Used	
		Airborne	Time at Origin**		1999	2000
February						
March						
April	**-7.177**	**-0.728**	**-6.448**	0.7659	2	2
May						
June	**-5.945**	**-0.515**	**-5.430**	0.7455	5	6
July	**2.742**	**0.639**	**2.103**	0.7540	5	6

*There was no data set with more than 40 minutes of delay for February, March and May. Results in bold type are statistically significant at the 1% level.
**Time at origin is defined as the sum of departure delay and taxi-out time.

The individual flight time analysis based on Model 1 shows that even though the airborne times improved slightly for URET flights in the after period, the much greater improvement was in the time at origin. This differs from the conventional wisdom that the primary impacts of URET would be to save airborne time by permitting more direct routings and efficient conflict resolutions. What mechanism could account for the observed reduction in origin delays? The most likely explanation is that, under certain conditions, the URET sectors were overloaded, leading to the imposition of ground delays for flights using these sectors, and that this phenomenon decreased under URET.

Given current air traffic management procedures, it is expected that flights originating from airports in or near the URET center regions would be the most severely effected. Model 2 was used to investigate this possibility. As was explained above, additional variables were introduced so that URET impacts could be differentiated by flight origin and destination. Figures A-1 and A-2 summarize the key estimation results for these models. They show, for each of 40 major airports, the arithmetic mean of the estimated URET impact on time at origin, over the five months from February through June—the months when two-way communication was not in effect for 1999. Figure A-1 differentiates the impact by origin airport, and Figure A-2 by destination airport.

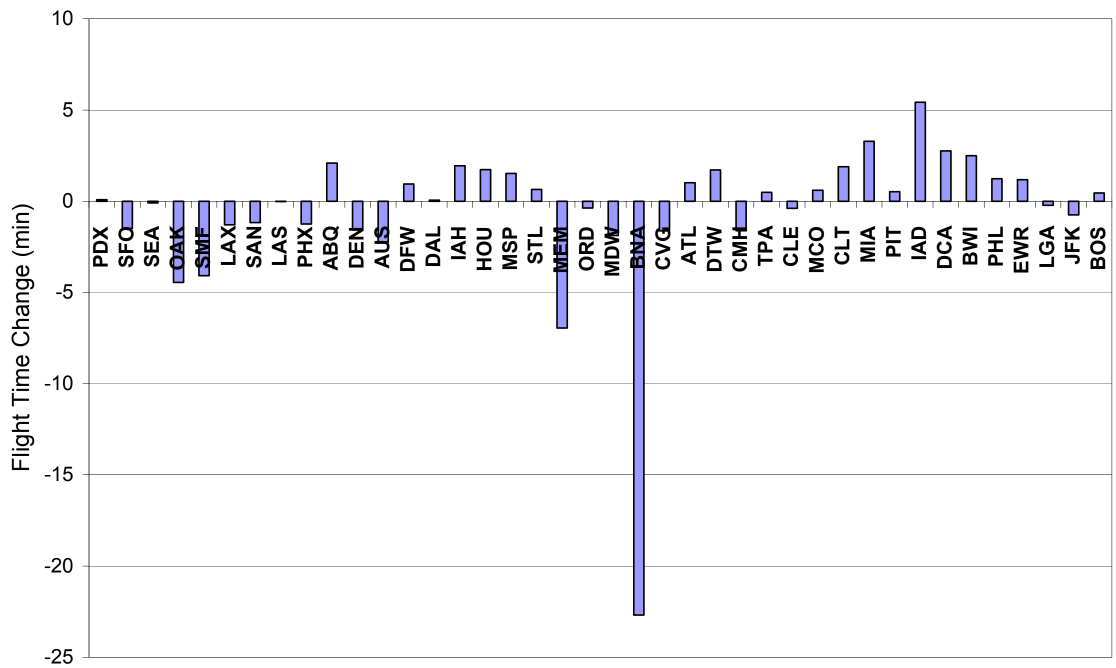

Figure A-1. Time at Origin Influence on Flight Times by Origin Airport

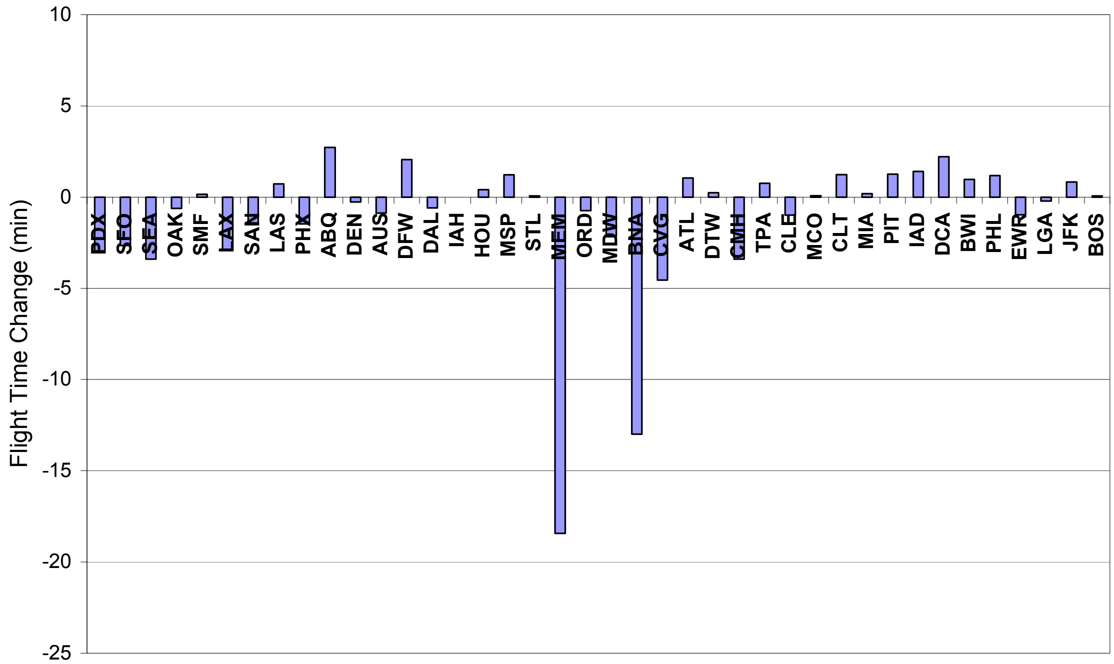

Figure A-2. Time at Origin Influence on Flight Times by Destination Airport

The airports in Figure A-1 and A-2 have been sorted by longitude, from west to east. URET apparently has the strongest influence on airports that are located within the URET centers: Memphis. Nashville, Cincinnati, as well as for some airports that are in the vicinity, like Chicago O'Hare and Midway. In contrast, the influence on time-at-origin for airports that are further away is generally less in magnitude. These results generally support the hypothesis that URET hastens aircraft departures by easing restrictions, such as miles-in-trail, for flights entering URET airspace from airports in the vicinity. There are some anomalies, however. In particular, flights to and from the West Coast appear to have had reduced ground delays, while airports along the Atlantic Seaboard appear to have been negatively affected. In addition, the magnitude of these effects is greater than we would have expected. It is possible that other, cotemporaneous changes to infrastructure or procedures could have influenced these data. NEXTOR researchers are continuing to study this possibility.

As a further check on the hypothesis that URET implementation has led to a decrease in departure delays, NEXTOR investigated whether URET Centers were able to accept traffic at higher rates after the July 1999 changes. Such increases could lead to the reduced restrictions that appear to be causing reductions in ground times. They therefore analyzed the time intervals (headways) between consecutive aircraft entering URET airspace in 1999 and 2000. From ETMS boundary crossing data they obtained the location and time of entry of each aircraft that used the URET Centers. The entry points were grouped according to the sector division of each center, which is shown in Figure A-3. The headways were calculated for each sector independently and then grouped on the Center level, thus making a headway distribution for each of the Centers. The 1999 and 2000 headway distributions for the ten busiest hours of the day (13-23 GMT) were then compared. A *t*-test was used to test the null hypothesis that the mean headway did not change. Table A-4 shows the distribution means for before and after periods, by Center, and the *p*-values from the *t*-test. Table A-5 presents the individual sector results.

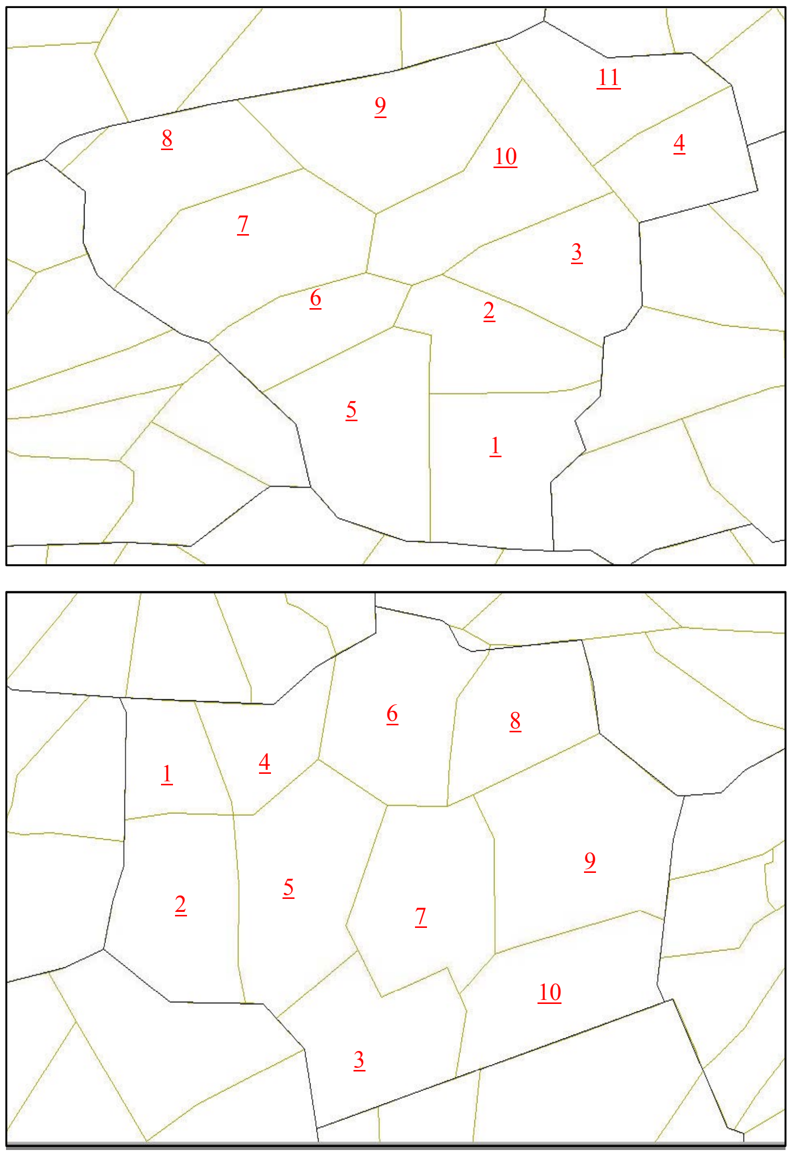

Figure A-3. Geographical Sector Division

Table A-4. Changes in Headways for URET Centers

ZID			ZME		
Distribution	Mean	P Value	Distribution	Mean	P Value
Before	1.249	0.0001	Before	1.780	0.0001
After	1.173		After	1.640	

Table A-5. Changes in Headways for URET Centers, by Sector

ZID					ZME				
Sector	**Period**	**N**	**Mean**	**P-value**	**Sector**	**Period**	**N**	**Mean**	**P-value**
1	Before	75916	1.300	<0.0001	1	Before	64411	1.420	<0.0001
	After	76480	1.260			After	76812	1.291	
2	Before	77638	1.272	<0.0001	2	Before	24359	4.094	<0.0001
	After	81249	1.179			After	31978	3.428	
3	Before	73602	1.349	<0.0001	3	Before	31592	3.134	<0.0001
	After	77008	1.253			After	36452	2.98	
4	Before	73578	1.344	<0.0001	4	Before	88589	0.980	<0.0001
	After	77437	1.237			After	105000	0.890	
5	Before	41931	2.533	<0.0001	5	Before	60129	1.540	<0.0001
	After	43820	2.364			After	71485	1.403	
6	Before	156000	0.569	<0.0001	6	Before	28148	3.551	0.0555
	After	158000	0.594			After	31592	3.483	
7	Before	10950	10.135	0.640	7	Before	36860	2.654	<0.0001
	After	10852	10.201			After	42609	2.507	
8	Before	120000	0.763	<0.0001	8	Before	76399	1.174	0.0060
	After	129000	0.686			After	84991	1.151	
9	Before	96518	0.983	<0.0001	9	Before	38399	2.552	<0.0001
	After	101000	0.912			After	44609	2.391	
10	Before	66233	1.525	<0.0001	10	Before	45876	2.078	<0.0001
	After	72054	1.355			After	56567	1.839	
					11	Before	89611	0.970	<0.0001
						After	109000	0.861	

From Table A-4 we can see that the average headways decreased in the after period. The headway decreases—which translate into increases in throughput rate—were 6 percent for ZID and 9 percent for MEM. Both of these differences are highly significant statistically. Table A-5 shows that statistically significant headway decreases have occurred in most to the sectors. The main exceptions are Sectors 6 and 7 for ZID, where headways have increased—significantly in the case of Sector 6. The Sector 6 change is noteworthy because it is also the sector with the highest number of entering flights and lowest average headways.

In sum, while previous benefits analyses have emphasized the value of URET in increasing the efficiency of aircraft routings, this analysis provides evidence of an equal or greater benefit in the ability of URET airspace to handle more traffic, with a resulting decrease in delays—mainly taken on the ground—due to sector overloading. These impacts are strongest on “bad” days characterized by high average delays throughout the NAS, and for airports in the vicinity of ZID and ZME. While most of these results are consistent with this theory, there remain a few mysteries, including why West Coast flights have benefited to the extent that the analysis suggests, and why Atlantic Seaboard flights have not. Research to address these issues is ongoing.